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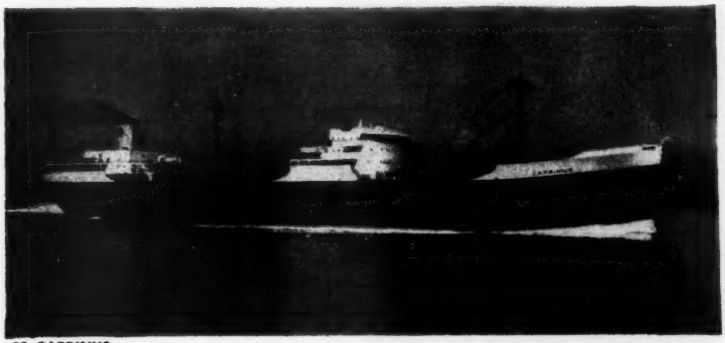

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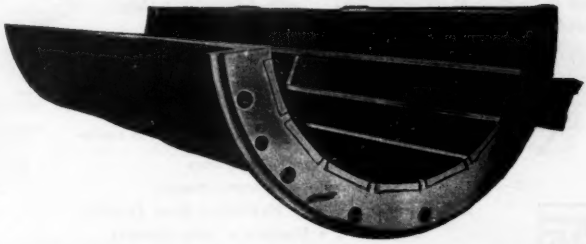

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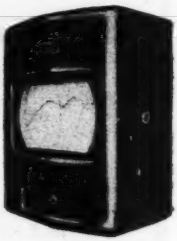

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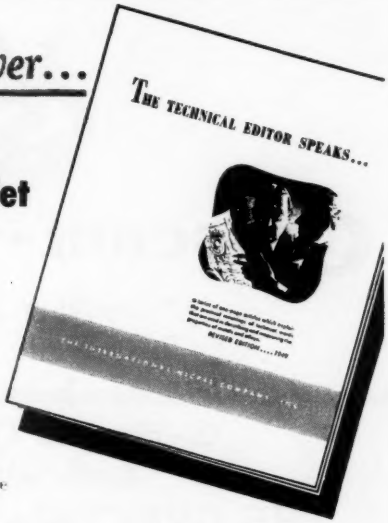

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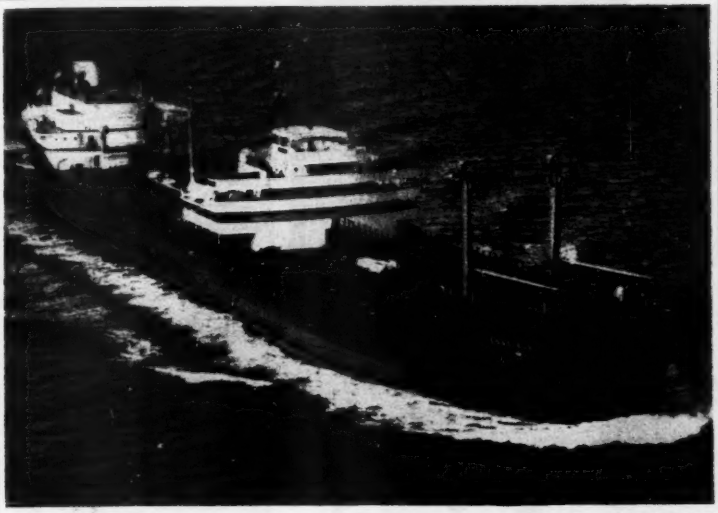

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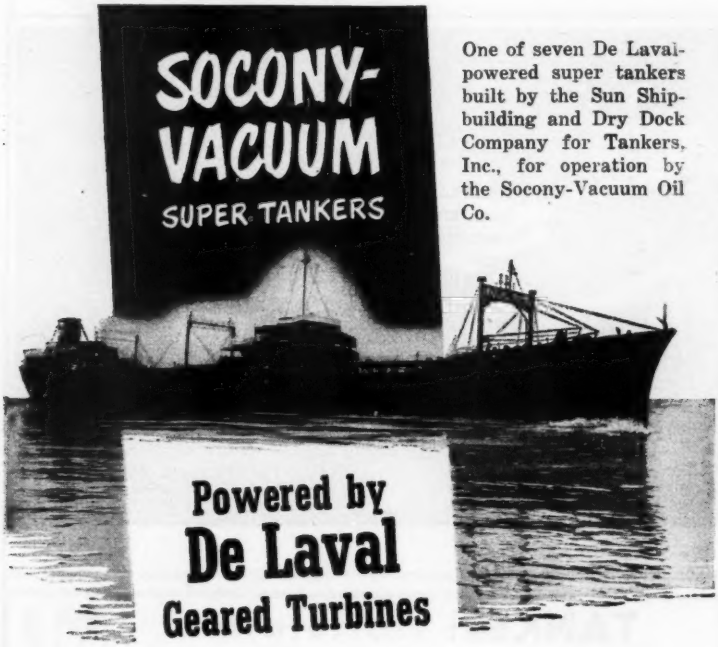

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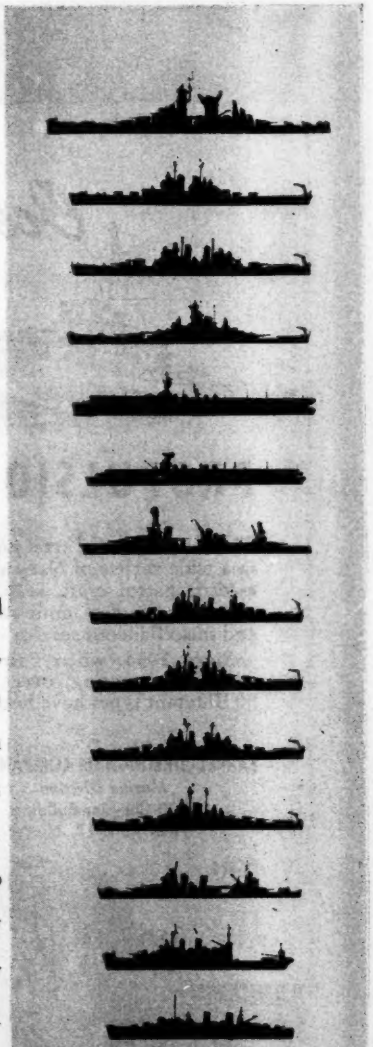

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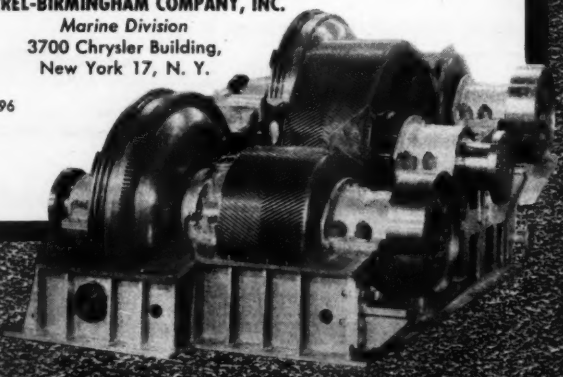

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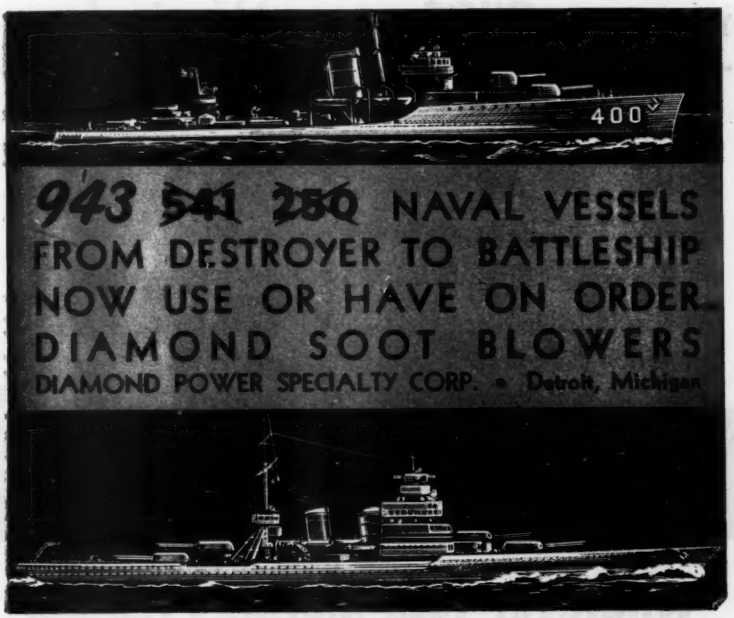
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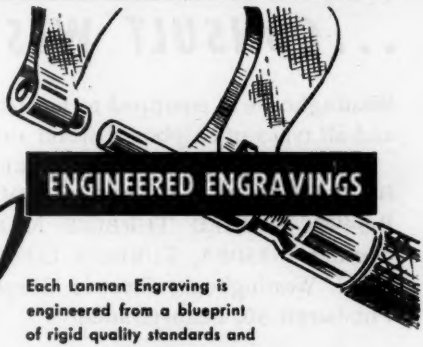

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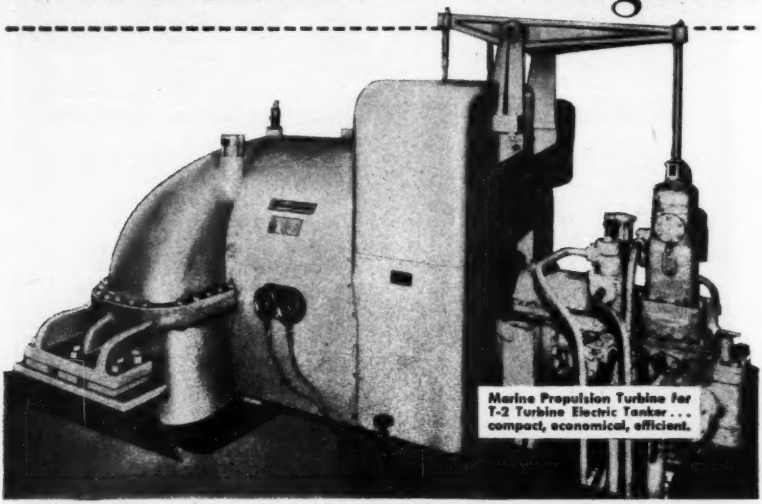

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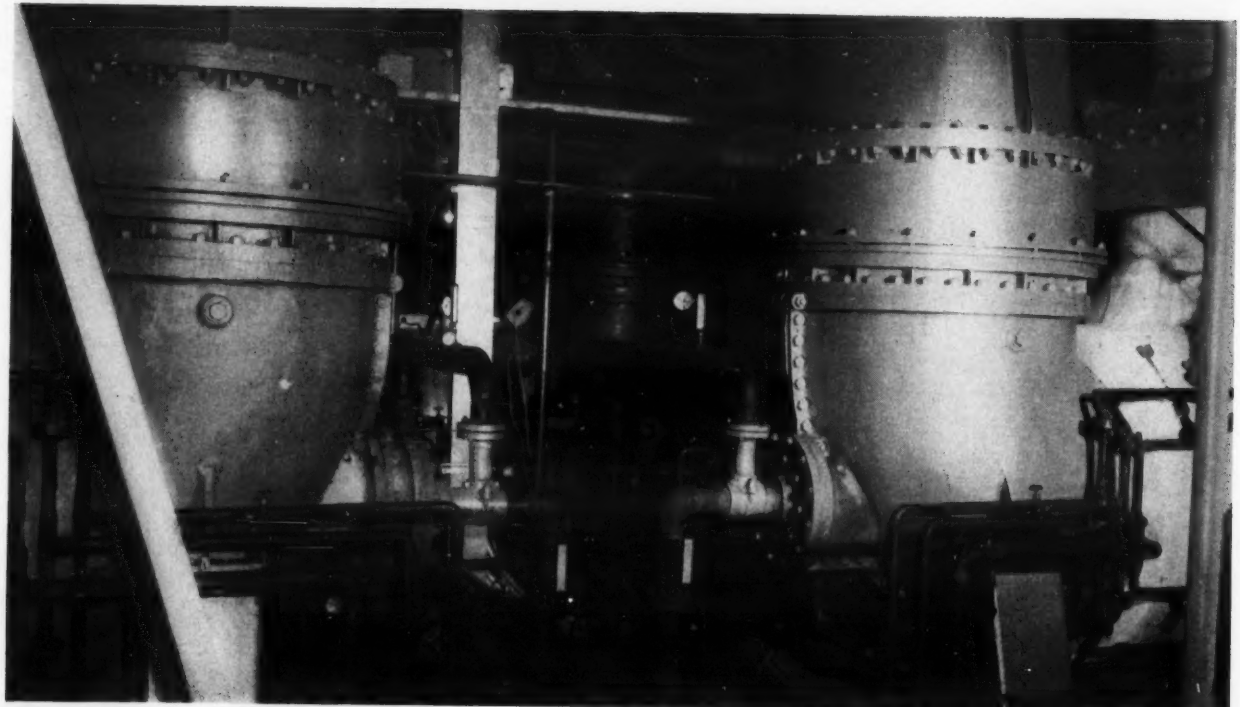

GAS TURBINE EXPERIMENTS UNDER WAY AT ANNAPOLIS, MD., NAVAL LABORATORIES

Official U. S. Navy Photograph

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JOURNAL

OF

THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

VOL. 62. NOVEMBER 1950. No. 4

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SECRETARY'S NOTES

ANNUAL MEETING

The Society's annual meeting was held on 3 October 1950. Nominations for officers and members of the Council and other business were considered. A more detailed report of the meeting will be found in the Association Notes.

FINANCIAL STATEMENT

The financial statement which is published in the Association Notes shows the expected continuation of the heavy loss of the last few years. It is expected that further loss will be sustained in 1950 since the measures which the Council initiated to improve the situation will not be fully effective until 1951. Those measures should restore the desired black balance to the annual account by next year unless we encounter another inordinate increase in costs. The Secretary does not care to join the host of experts who are predicting future price trends. We will have to consider conditions

as they are encountered. We have a fairly wide range of controls through size of the JOURNAL. Every effort will be continued to maintain the quality of the publication and at the same time to effect a financial balance.

CORRESPONDENCE

In a sense, the Secretary has a real complaint because of the small number of members who write, commenting on the JOURNAL. The modifications in format and scope which were approved by the Council at the beginning of the year were arrived at with the benefit of practically no reader comment.

The two letters which are published below are examples of what we like to receive. They would be just as welcome if the tone was one of constructive criticism.

The first is from Captain A. C. Stott, U.S.N., Retired—a member since 1909. He writes:

7062 Vista del Mar
La Jolla, California
July 29, 1950.

The Secretary-Treasurer,
American Society of Naval Engineers,
Navy Building, Constitution Ave., N. W.
Washington, D. C.
My dear Hamilton:

I greatly appreciated the letter of July 25th in which the Society was pleased to acknowledge my membership of 41 years. It is also very kind to offer to place me on the list for free reception of the JOURNAL from now on.

However, I do not care to avail myself of this very generous offer. To be perfectly frank, the only reason I have resigned from the Society, is that advances in engineering and the kindred sciences have progressed so far and so fast in the past few years that I can no longer claim to even be familiar with much of the nomenclature employed in current reports and technical articles. The reading of the JOURNAL, which so long as it comes I feel that I have to do, has ceased to be of either great profit or pleasure.

After 44 years of active duty, and five years as a Marine Surveyor around New York harbor, I feel that my retired years are a good time in which to slack off a bit, and the JOURNAL is one of the places where I am going to relieve my eye and my mind!

It is a far cry from my first practice cruise with the horizontal, thwartships, cross-compound engines of the old *Hart-*

ford, to the cathedral-like silence and apparent immobility of the engine room of my last command, the *Idaho*.

The next generation will no doubt find equally great steps from our present cherry-red main steam lines and high-speed Diesels to the atomic power plants of the near future.

Through all the past the Society has led development on a steady course, and through the future it will carry on in the same way. It is a great satisfaction to feel that I have had a part, however minute, in contributing to the successes of the past.

Sincerely,

A. C. STOTT,
Captain, USN (Ret.)

The other is from Rear Admiral Wat Tyler Cluverius, U.S.N., Retired. Admiral Cluverius is at present President of Worcester Polytechnic Institute. His letter is:

WORCESTER POLYTECHNIC INSTITUTE

WORCESTER 2, MASSACHUSETTS

Office of the President

27 June 1950

Captain J. E. Hamilton, U. S. Navy,
American Society of Naval Engineers, Inc.,
Bureau of Ships, Navy Department,
Washington, D. C.

My dear Hamilton:

Although a very old member of "Naval Engineers", I have not been as careful a reader of the JOURNAL in recent years as I could have been.

Last night, however, I began the May number and found it especially rewarding. Olch's article on Bilge Diving, in words of one syllable, is valuable in these days when the service afloat is required to do all the conserving. The illustrations add much and the format generally is most acceptable.

Noticing the advertisement of the Kingsbury Machine Works, you may not know that Kingsbury, who came out of the University of New Hampshire, was long a member of the staff of the Mechanical Engineering Department here. The apparatus used in connection with the first Thrust Bearing is still maintained here and some of it is in instructional use.

A few months ago, Lewis W. Kenney (New Hampshire, '99) asked for the various portions of the apparatus for the new Engineering Laboratory at the University and we are

perfecting the necessary arrangements. Kenney, who has long been a member of Naval Engineers (I knew him first at Cramps Shipyard many years ago) could produce an excellent paper on Kingsbury, whose bearing was developed at Worcester Tech and, in that fact, we take great pride. It is still the best in the engineering field.

My congratulations on the excellent professional work in which you are engaged, and with warm personal regards,

Sincerely yours,

WAT TYLER CLUVERIUS,
Rear Admiral, USN (Ret.)

ARTICLES

This issue contains two articles which can be used as examples of the manner in which the Society has carried out its mission through 62 years of gargantuan engineering development. It is somewhat surprising that we can still make that claim when today there are so many more worthy competitors striving to get original technical papers than there were during the first half of the Society's life.

The first is a new departure, a staff article, but it is built around two original papers, one anonymous, the other a letter by Fay. Both hark back to Huber's paper which was published in May. Incidentally, the Huber article was prepared specifically for the Society at the Secretary's invitation and we take some pride in the fact that it was published, complete, in French (but without acknowledgment to the Society) in the 22 July 1950 issue of the Swiss publication SCHWEIZERISCHE BAUZEITUNG.

The point to be made here is that the JOURNAL published a great many pertinent papers covering the transition from reciprocating engines to steam turbines and again covering the rise of the internal combustion engine and its adoption for main propulsion in its appropriate field. Only time will tell how much the JOURNAL's article will have to do with the next shift whether it should be to gas turbines, to atomic power or to something else.

The second article is the one on Titanium. Here again we must share the field with many others. However, when the final story on titanium is written it can be expected that a full bibliography on the subject will perforce include ASNE references.

Members and others who have publishable information or IDEAS in either of these fields or in any other of the many engineering advances which are in gestation are in a position to claim a place in engineering history by making their knowledge available to readers of the JOURNAL.

PART ONE

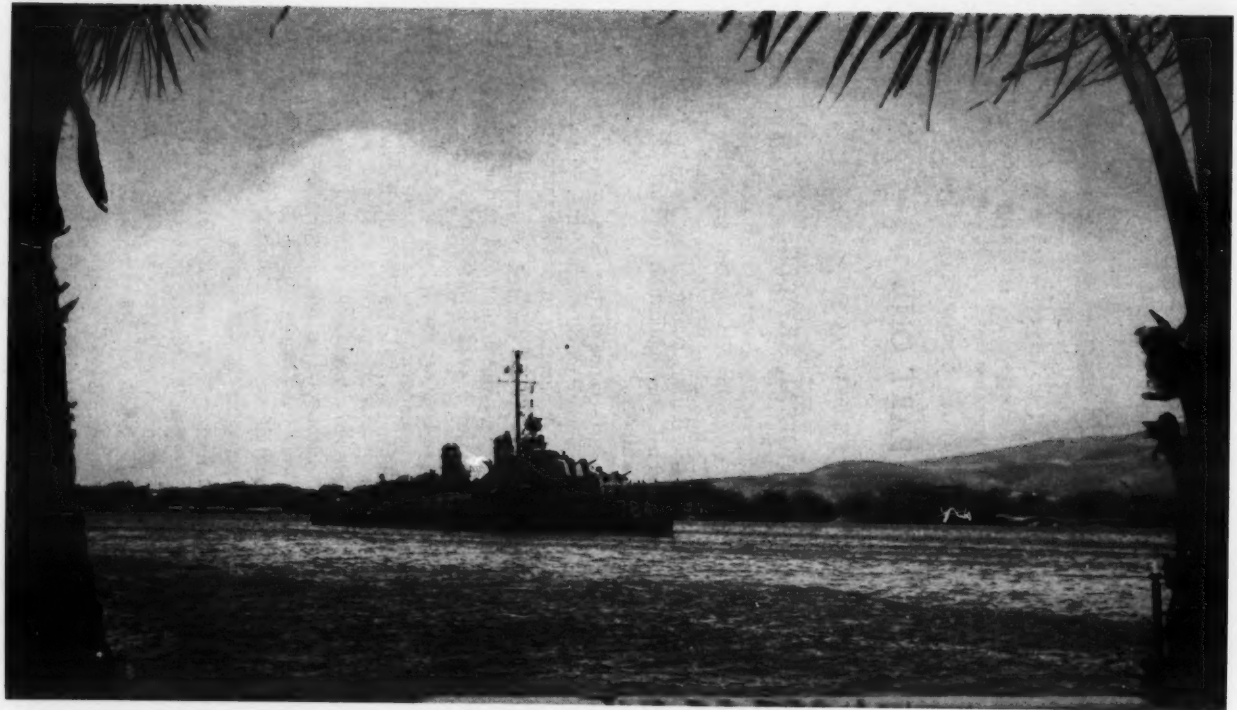
ORIGINAL ARTICLES

The articles which the Editor, acting under the supervision of the Council, has accepted for publication in Part One are the original works of the authors.

They are offered in furtherance of the Society's raison d'etre: to further the advancement of naval engineering. Discussion of any article is invited for publication in a subsequent issue.

Permission to reprint is freely granted on condition that *full acknowledgment is given* to the author and to the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS.

All articles which have been written by naval personnel and are published herein carry the personal view of the authors and, unless specifically so stated, do not express the official views of the Navy Department.



DESTROYER ENTERING PEARL HARBOR

Official U. S. Navy Photograph

CURRENT PLANNING FOR SHIPBUILDING

REAR ADMIRAL FREDERICK E. HAEBERLE, USN

THE AUTHOR

Was born in Missouri in 1893. He graduated from the U. S. Naval Academy in 1917. He served in World War I as a junior officer aboard the USS *Wyoming* with the 6th Battle Squadron, British Grand Fleet. He is a graduate of the Naval Academy and received his Master's degree at the Massachusetts Institute of Technology in 1921. He became a Rear Admiral in November 1945. From 1942 to 1945 he was Head of the Design and Construction Branches of the Bureau of Ships, Navy Department, responsible for the design and construction of all naval vessels. From 1945 to 1949 he was Commander of the New York Naval Shipyard. He holds the World War I and II Victory Medals, the Legion of Merit, Gold Star in lieu of second Legion of Merit and various theater decorations. Admiral Haeberle is at present on duty in the Navy Department, serving as Assistant Chief of the Bureau of Ships for Ships. He is President of the Society.

NOTE: This article is based on an address made by Admiral Haeberle to the Industrial College of the Armed Forces and the National War College on 27 April 1950.

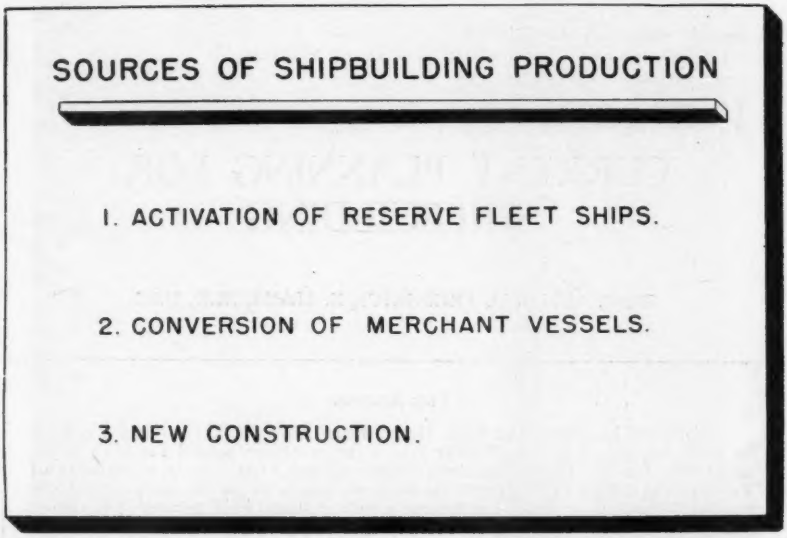
Shipbuilding production covers a pretty wide territory—too wide, I assure you, to really do it justice in this short article. But I shall try to cast out the nuts and bolts of detail and focus your attention, if I may, on the highlights. I will take a tip from the old-fashioned experts in the stripping business by eliminating enough of the things to command your attention and keeping enough to cover the substance.

The Bureau of Ships of the Navy Department is responsible for the design, construction, conversion, and maintenance of all combatant ships, and of all naval auxiliaries not under the Military Sea Transportation Service. The Bureaus of Ordnance, Aeronautics, Supplies and Accounts, and Medicine and Surgery contribute ship components and equipment as their names imply, but the over-all responsibility for a balanced design and for the material condition of our naval vessels is vested in the Bureau of Ships.

Shipbuilding production is the responsibility of the Chief of the Bureau of Ships, who has additional duty as Coordinator of Naval Shipbuilding.

Shipbuilding production will be

Chart 1


SOURCES OF SHIPBUILDING PRODUCTION
1. ACTIVATION OF RESERVE FLEET SHIPS.
2. CONVERSION OF MERCHANT VESSELS.
3. NEW CONSTRUCTION.

treated in a broad sense to include three primary sources of producing naval ships—Chart 1. "Sources of Shipbuilding Production": (1) activation of Reserve Fleet ships, (2) conversion of merchant vessels, and (3) new construction.

Before analyzing the nature of these sources and their potentialities, it might be well to look at the probable demand for shipbuilding production in another world emergency. I cannot make any statement as to size of the program. However, considering the many ships which have been disposed of since 1945 and the tremendous technological advances which have been made in the weapons to be carried or to be used against ships, it should be apparent that this demand may approach that of World War II when measured by industrial impact. This prospective demand seems to me like a reasonable one; that is, if we expect the Army to do appreciable fighting on other than our home soil.

At first glance, it would seem that a requirement for ships approaching that actually produced in World War II is feasible and attainable. But there are important differences to consider. World War III ships will be larger, more complex, and considerably more costly to build. The trend to increased size and cost in ships and planes is dictated by the complex interplay of offense and defense, of measure and countermeasure.

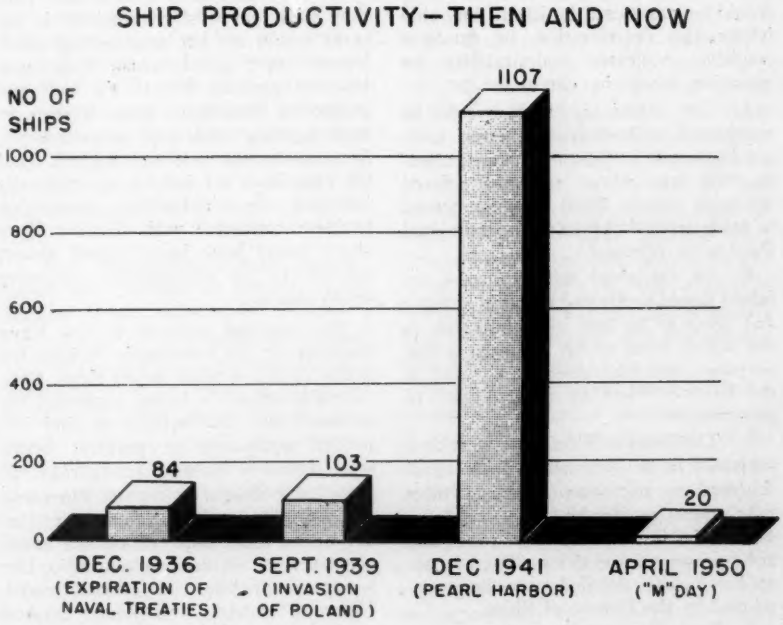
Another difference is the timing in shipbuilding production. In World War II shipbuilding was off to a running start. Nuclei of skilled builders were formed, developed, and enlarged well before German submarines opened fire on American vessels. Today the shipbuilding industry may not be sick but it is certainly undernourished. Let us take the patient's pulse—see Chart 2. "Ship Productivity—Then and Now." Since 1945, the shipbuilding industry has been slowed to the tempo of the early 1930's when the imminence of war seemed considerably less than it does

today. If an enemy should strike tomorrow, this country would have one-fifth of the ships building that we did when Germany went into Poland, one-fiftieth of the ships building when Japan struck at Pearl Harbor.

Although the United States may need fewer ships than in World War II, do not expect them as soon as you got them in the last war. Overseas shipment of fuel, men, and materials in quantity to follow up the atomic bombing of strategic targets will have to await shipbuilding production, itself hampered by strategic bombing from the enemy.

From this general picture of the probable demand and the present supply, I shall turn to a more detailed examination of the three sources of shipbuilding production; namely, activation of Reserve Fleet ships, conversion of merchant ships, and new construction.

Chart 2



THE RESERVE FLEET

While World War II was still under way, and, in fact, before the course of events assured us that victory was in sight, the Navy Department undertook a technical study of the proper steps which should be taken to preserve the country's investment in naval vessels when demobilization became in order and common-sense budget consideration required that the operating Active Fleet be reduced to a fraction of the active wartime fleet. It was recognized that the billions of dollars which had been spent for naval vessels represented a

true taxpayer's investment, and, more important from the technical military viewpoint, these ships represented thousands of tons of material and millions of man-hours of labor which had been expended and could never be replaced.

Briefly, the original plan went something like this:

1. Military consideration would be given to the various types of ships. Any type which seemed not to warrant retention would be eliminated right at the beginning and sold for scrap or other purpose.

2. Of the remaining types, each ship would be considered by itself. Any ship whose age, deterioration, or damaged condition indicated undesirability for retention would be eliminated.

3. The remaining ships would be considered on both economic and technical grounds to determine the numbers in each type whose retention offered optimum return. Then selection would be made from that type of the individual ships to be retained.

4. All the ships selected to be retained would be divided into two groups: (a) those to be kept in commission in the Active Fleet or for training or test purposes, and (b) those to be kept in the Reserve Fleet in a high state of preservation.

5. The Reserve Fleet ships were then supposed to be overhauled by a naval shipyard as necessary to make them fully operative, to be inventoried for deficiencies in on-board spare parts, and to be preserved and dehumidified in accordance with detailed procedures developed by the Bureau of Ships.

6. Each Reserve Fleet ship was to be tied up in a berthing area with a roving naval crew assigned to a group of ships. This crew would make periodic inspections, check dehumidification machinery, maintain preservation, and train for activation of the ships in an emergency.

7. Finally, every effort would be made to keep the Active Fleet fully modernized and always ready for instant combat service.

The ideal plan that I have described would have provided that every ship in the Reserve Fleet could put to sea in less than 30 days, ready to operate in combat with the equipment which the ship had installed on its last active day of service. The actual ready-for-sea date would depend upon the time a trained crew reported on board. In every case the vessel would be almost immediately ready for use to train her crew when assigned.

It was recognized under this plan that each year a ship remained in reserve would see her approaching obsolescence as a naval vessel. This obsolescence pertains less to the hull and propelling machinery than it does to such fighting equipment as search radars, armament, and fire control. Had the plan been carried out as originally intended, the shipbuilding production problem connected with Reserve Fleet ships would have been limited almost entirely to the question of correcting obsolescence.

The material bureaus of the Navy Department are continually looking for better things to make better ships. Considerable effort is being expended for research and development to find improved equipment to perform better some function already incorporated in ships, or to deliver or counter some new weapon. These developments are incorporated into ships which are under construction, so that any new ship, like a new automobile, is a current model. Many of the new developments are not worked into existing ships to increase their effectiveness. The improvement is sometimes of such a nature that its cost would be prohibitive in the older ships. On the other hand, it would be folly not to install the newly developed equipment in new ships.

There are some developments, however, that must be made to the older ships to make them usable for their

original and intended purpose. Such developments include the employment of heavier and faster aircraft, augmented fleet requirements for radio communication and countermeasures, increased range of detection required to combat faster enemy aircraft, etc. The installation of new weapons in an older ship may make it possible to improve her effectiveness a great deal. An important example of this kind is the possible extension of attack range by the substitution of rockets or guided missiles for projectiles fired from guns. The field of research and development reaches into every feature of our ships. It is difficult to generalize, but it is safe to say that certain material improvements will have to be made in Reserve Fleet ships before they can be used in combat. A great many more improvements could be made to increase the effectiveness of the older vessels and thereby reduce the total number of ships required in the Navy.

I have just discussed what was intended and planned to happen in the creation of the Reserve Fleet. Now I will tell you what actually did happen.

When the end of World War II came, everything went according to plan until the returning ships began entering port for overhaul, inactivation, and preservation. At that point the discharge of both officer and enlisted personnel became so rapid that it was impossible to accomplish the planned preservation work with the military personnel on most of the ships. Preservation had to be done by civilians in naval shipyards. Initially, those ships which needed overhaul were made available for shipyard repairs so that they would attain the full operability planned. As money tightened up, these overhauls were progressively reduced in scope until a great many ships were actually placed in the Reserve Fleet without any overhaul. They were not restored to a reliable operating condition.

The preservation work which had to be turned over to civilian labor in shipyards diverted money from repair work to preservation. In addition to the financial effect, there was a limitation on the total civilian labor force available. However, the job of preservation was effectively done. It is reasonably safe to say that our ships in the Reserve Fleet have been preserved so that serious deterioration will not be experienced.

Because repairs on many ships were not made prior to inactivation, a new plan was drawn up to fit the economic situation. Under this plan, every ship in the Reserve Fleet was scheduled for an overhaul once every five years. This schedule would have permitted accomplishing any repairs which had been deferred at the time of inactivation. This plan went along on schedule for about two years. In the fall of 1949 money limitations forced the abandonment of this five-year overhaul plan. The primary effort then became to preserve the integrity of the watertight envelope of each ship so that dehumidification of the interior will prevent further deteriorations.

Another effect of the rapid discharge of military personnel was the difficulty in getting an accurate inventory of onboard spare parts and the preparation of requisitions to fill deficiencies. At the same time, the far-flung supply system which had been necessary to support the Navy was demobilized so rapidly that much of the material could not immediately be handled by the peacetime supply system. The supply system was reduced to peacetime operational level before it could process the thousands of requisitions and furnish material required to fully outfit the Reserve Fleet. At this time, however, requisitions are mostly prepared. They are ready to release, to start the flow of material to the Reserve Fleet when mobilization comes.

Had demobilization gone as originally planned, who knows whether the optimum condition of the Reserve Fleet would have been adequate compensation for the delay in getting manpower back into peacetime pursuits or whether the drain on the Treasury which a slower demobilization would have caused would have been justified? It is a good bet that, when political and economic factors are considered, the proper action was taken. The present status of the Reserve Fleet comes under the head of a calculated risk we must take.

It may be good "flag waving" to talk about getting the Reserve Fleet into action overnight. It is better for you and me to remember the practical aspects I have described. With this understanding of the present and prospective condition of ships in the Reserve Fleet. there are three things which must be keyed together to produce active ships ready to fight: (1) design, (2) material condition, and (3) manning.

By "design" I mean full consideration and decision by both technical and military minds to determine what changes—principally what additional installations and replacements of equipment—have to be made in each ship before it will be usable by a tactical commander for a wartime military function. As an example, if an LST is required to transport a Marine Corps tank battalion, and if the tanks now used by the battalion are of a new design which cannot be accommodated in the LST until certain changes have been made, I would consider that the ship is obsolete and not deployable until the alterations have been made.

By "material condition" I mean the state of maintenance and repair of the ship's hull and of installed machinery and equipment which is necessary for her to operate. This material condition is quite apart from the question of obsolescence. As examples, ship whose shaft clearances have reached a point where only a few days of reliable operation can be expected, or a ship which has two out of four main feed pumps inoperable, cannot be considered as ready for use in combat.

By "manning" I mean that officers and enlisted men in sufficient numbers and of proper qualifications are on board to operate the ship in shakedown operations. This means the training of the entire crew, including raw recruits, with the ship at sea.

The planning and scheduling of the three elements—design, material condition, and manning—must consider different factors, but all these factors can be summarily designated as lead time. In this case, lead time can be considered as the interval of time between the moment of decision and the accomplishment of a purpose. If the moment of decision is M-day, and it certainly is so far as the country as a whole is concerned, then all lead times are variables depending on many things but all collectible under the general term "planning." If intelligent planning in the area under consideration has been completed and is being kept up to date, any lead time from M-day is a minimum. If all planning must start on M-day, the lead time is naturally a maximum. The variation here can be very wide, possibly as much as two years. As it happens, what I have designated as design will doubtless be the controlling element in the timing for getting reserve ships ready for full active service. Design is also the area in which most effective planning can be accomplished. It is possible to theorize that good planning accomplished in design matters will shift the control from design to material condition and probably in many cases to manning.

To replace the vessels of the Reserve Fleet today would cost about 18 billion dollars. The cost to inactivate, preserve, and dehumidify these ships was less than 1 percent of the cost to build them. The cost to activate, repair, and modernize these ships will be considerably less than the cost to build, and to do so will be considerably quicker.

CONVERSION OF MERCHANT VESSELS

The second primary source of naval shipbuilding production is the conversion of existing merchant ships to naval use. Under current mobilization planning, every merchant ship afloat, both active and reserve, is being examined and earmarked for specific service in event of war.

For those merchant ships designated for conversion to naval vessels, existing naval ships are being selected as prototypes to represent the best practices based on World War II and current developments. So far as funds permit, drawings will be made and bills of material prepared to have immediately available contractual and technical information for release to the shipbuilding industry at the same time that the ships are sent to the yards for conversion.

In new designs of merchant ships prepared under the United States Maritime Commission, basic national defense features are incorporated by the expenditure of national defense subsidy allowances. Such features are acceptable only if they do not make the design unattractive to the ship operator or penalize him unduly in competition. For example, the machinery plant may be designed for operation with a fast amphibious task force, whereas a lower speed would be more economical over the particular trade route in which an operator is interested. Close liaison is maintained with the Maritime Commission to foresee and plan for conversion from merchant to naval use.

Current construction of merchant ships is far short of the minimum requirements for an orderly peacetime replacement and for conversion to naval use in an emergency. Even with the conversion of all existing passenger and passenger-cargo ships, and with the utilization of some 50 transports under the Military Sea Transportation Service, the combined troop-lifting capacity would fall short of the World War II level of requirements by approximately one-half. Of the 100 or so ships potentially available for use as troop transports, 21 are over 25 years old and only 52 are in active operation. A shortage in troop-lift capacity can be partially met by the conversion of cargo ships as was done out of necessity in World War II. Such conversions are time-consuming and costly, and they are made at a sacrifice of the cargo ships themselves, for which the need would probably be only slightly less urgent than the demand for troop ships.

An exception to the present lull in shipbuilding is the private construction of tankers. Recently 32 new tankers have been completed and 23 others are still under construction. These replacements are sorely needed, as most of our tanker fleet is the T-2 type built during the war years.

The position of our country in regard to dry-cargo vessels is becoming increasingly critical. By far the greatest part of our dry-cargo fleet is composed of slow Liberty ships. The higher-quality cargo vessels of the C-2 and C-3 types were nearly all built between 1939 and 1946. Two types of modern cargo vessels are being designed. Unless the current shipbuilding program is supplemented by dry-cargo vessels to replace war-built tonnage, this country will not have the balanced merchant fleet which national security demands.

We do not yet know of any satisfactory substitute for surface ships for lifting the great quantities of things any war will require to be moved between the land masses of the earth. The ocean, like the air, is a self-lubricated, cost-free highway. The ocean has the advantage over the air of supporting loads by displacement. The ratio of useful lift to drag is one measure of efficacy of transport. This ratio is a hundred times greater in a ship than in an air-

plane, which does not make use of the cleavage surface between fluids of different densities for support.

Every indication is that the replacement and augmentation of the merchant fleet will form a major portion of the shipbuilding production requirements in an emergency.

NEW CONSTRUCTION OF WARSHIPS

To perform the functions allocated to the Navy by the Joint Chiefs of Staff, new construction of warships starts with the development of characteristics by the Chief of Naval Operations. Working with the Bureau of Ships in successively more detailed feasibility tests, the Chief of Naval Operations develops the characteristics, which specify the principal military features, such as sustained speed, cruising radius, armament, enemy detection, mobility, ammunition, and communications.

The Bureau of Ships is responsible that ships float stably, move at specified speeds for planned distances, respond to the will of its commanding officer, carry and service assigned weapons, survive damage to keep these weapons in action as long as practicable, function internally and with other units, and provide conditions of habitability which permit every man on board to remain physically and psychologically fit to perform his duties.

In peacetime principal design effort is directed toward the development of prototype ships in which new weapons and defenses can be evaluated under service conditions. This design and evaluation cycle is applied also in the alteration of existing naval vessels to improve their performance. It is applied also in the conversion of existing naval vessels to a different type with a different function. Conversion work may not only establish the suitability of the design for mass conversion if need be but may also serve to develop and test new weapons and equipment in service before designing and building a completely new ship around them. An example of this procedure is the test of antiaircraft guided missiles from the seaplane tender *Norton Sound*. Exhaustive service tests will be conducted before a guided-missile ship to carry a main battery of these missiles is built for the purpose.

As it is impracticable to build samples of all new and converted types for which a need is anticipated, the Bureau of Ships is developing a scheme for planning conversion and construction in a realistic manner, a scheme that will reduce productive lead time when mobilization begins. This process follows normal step-by-step procedure in about the following way:

1. The Ship Characteristics Board in the Office of the Chief of Naval Operations furnishes basic requirements.

2. The Bureau of Ships design force develops contract plans and specifications. If assistance is necessary, a contract is made with a shipbuilding design agent to prepare plans for consideration and approval by the Bureau of Ships before proceeding with the next step.

3. The contract plans and specifications are furnished to a design agent. He proceeds with the detailed design to whatever extent is necessary to permit developing an erection schedule for the ship and specifying the principal components.

4. The Bureau of Ships selects prospective shipbuilders to undertake the construction of the ships which are in the mobilization program. The Bureau works with each of them, determines all steps which must be taken to improve or modify their facilities, and gives them data on which they can estimate their manpower requirements and plan their production.

5. The design agent and the Bureau of Ships together line up prospective manufacturers for the components the contractor will have to furnish.

6. Based on the required military characteristics, and on the current status of research and development, the Bureau of Ships prepares specifications for government-furnished equipment for the new ships.

7. The Bureau combines the requirements for new ships with like requirements for converting existing ships and then proceeds to phantom procurement for the total requirements.

The procedure I have outlined is complicated in two ways. First, there is a tremendous amount of it. The procurement incident to mobilizing an expanded fleet reaches into every industry and every channel of trade. It involves hundreds of thousands of items, and millions of procurement papers. Naturally, the bulk of these papers cannot be handled in advance because of personnel ceilings. It would be necessary to employ thousands of people, virtually the same number that would be needed if procurement were actually under way.

What we can do and are doing is to develop our specific material requirements on the assumption that the building program will start tomorrow morning. The requirements for each type of equipment are listed for each three-month period. These estimates are fanned out to industry. The estimates give each manufacturer enough detail so that he can plan on what he will need in machine tools, floor space, personnel, raw material, and so forth. As time passes and new developments make earlier equipment and earlier ships obsolete for planning purposes, our estimates to industry are revised. When the time comes, many of our material estimates can be immediately translated into contracts. On other estimates, we will have a lag due to recent developments, but the manufacturer will know the approximate type and quantity of equipment we will need. Much of his planning can go into the execution stage while we are getting out detailed drawings and specifications for him.

Because of current personnel ceilings and the tremendous amount of detail involved in planning material requirements, it has been mandatory to develop a system which uses machine tabulating card methods. Changes in the number and type of ships in the proposed fleet, as well as changes in the time when new ships are to be ready for sea, can now be handled by machine tabulation. The machine will turn out the quantity of each size and type of material by specific stock number. It will show when the material is needed. This mechanical method permits rapid recalculation of any change in basic plans.

The second real difficulty, which is probably the harder, is the reluctance to make technological decisions in advance. It is not easy to make a decision today which is, in effect, "If we mobilize tomorrow, this is specifically what we will buy." Decisions must be made before sweeping orders for manufacture can be placed. The Joint Chiefs, the Chief of Naval Operations, and the Chief of the Bureau of Ships must make binding decisions. They know that such decisions will start a chain of operations leading to ultimate manufacture which might, under certain circumstances, interfere with the procurement of a better item if it is developed later. They realize that, when M-Day actually arrives, it will bring with it the final moment of decision.

In this regard, you might visualize two extreme conditions, and I assure you that both are very extreme.

In the one case, no decisions have been reached. M-day labor is standing by to be employed on war production. Industry is standing by to receive orders for war production. Procurement personnel are standing by awaiting to be

told what to buy. Design people are standing by awaiting to be told what to design. Bureau chiefs are standing by, probably on the Chief of Naval Operations' doorstep, to find out what plans will go into effect. The Chief of Naval Operations is sitting with the Joint Chiefs waiting for word from the Secretary of Defense. The Secretary is at a Cabinet meeting on Pennsylvania Avenue trying to find out what the President will authorize.

That extreme may appear to you to be far-fetched, but to those of us who were in the Bureau of Ships in 1940 and 1941 it is a very real possibility.

The other extreme is admittedly ideal. The enemy is known. His equipment and plan of attack are known. Decisions have been made as to mobilization requirements. They have been translated into logistic requirements in necessary detail. Authorizations have been issued so that the Chief of the Bureau of Ships is free to act on initiating procurement. Designs and specifications have been prepared and made known to prime contractors. The prime contractors have agreed to definite production schedules. The Munitions Board has confirmed the agreements. Information is in the hands of prime contractors in such a form that simple telegraphic letters of intent can start the wheels of the shipbuilding industry turning.

In the first instance, where no advance decisions have been made, any procurement would represent the latest technological development as of that date. There are certainly some types of items where this is the only possible procedure. However, if the application was universal, the delay in getting things started by this approach would be months, and the actual launching of the first post-M-day ships might be delayed as much as two years.

The second picture, where all decisions have been made ahead of time, presents the optimum for getting equipment flowing from factories to ships. Against it is the accepted fact that the equipment produced would be at least as far behind technological advances as the calendar period gained in production. If that is the only disadvantage, the choice resolves itself into a case like the following: If a destroyer delivered 24 months after M-day embodies the latest possible technological developments, will it be of more value in an antisubmarine campaign than a destroyer delivered 12 months after M-day and deficient in some of the latest developments? I recognize that no general answer is possible. The master planners must make decisions on matters of this kind. These decisions will be just as final as similar decisions made in wartime.

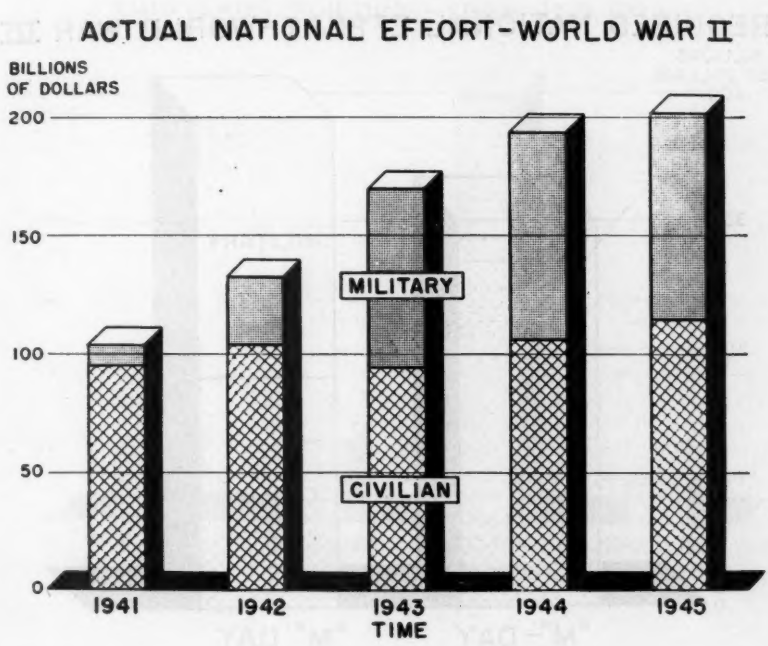
Mobilization planning calls for far greater effort to assure alertness to developments than is necessary in wartime. In wartime we have an enemy and contacts with him to keep us alert. In peacetime we have only our knowledge of technological developments and our imagination as to what they can mean in war. It is a real problem.

You may be interested in some of the current trends in ship design which will affect mobilization requirements.

During World War II Diesel-driven generator sets for shipboard uses were required in large quantities. A program to develop a standardized line of the electric ends of these sets has resulted in standard ratings. The generators are interchangeable. They are suitable for couplings to Diesel engines of types already in service. The program includes sets from 30 kw to 1,000 kw and has resulted in increased industry preparedness in the form of approved designs ready for production.

Shipboard electric motors were one of the very critical items in World War II. An important factor was the lack of standardization and the variations inherent in motor design. Industry produced the motors on a job-shop basis

Chart 3



because of the large number of designs needed by the driven machinery. In a single horsepower rating of an AC induction motor, we now have 192 different designs in the fleet. A standardized line of motors is being developed which will drastically reduce this number and at the same time will increase the interchangeability of repair parts.

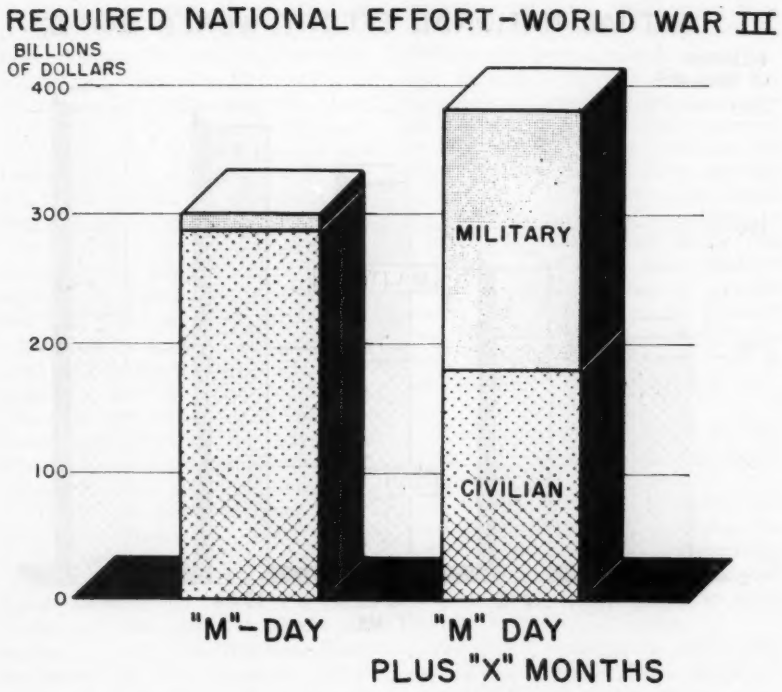
Design developments require flexibility in mobilization planning. An example is the increasing use of more highly alloyed steels with higher strength-to-weight ratios. The trend in this direction is dictated by the need for saving weight and space in the equipment and machinery so that increased armament and new weapons can be carried without increasing the displacement of a ship.

The latest prototype ship designs will use higher steam temperatures and higher pressures than those of World War II ships. This trend requires the use of more highly alloyed steam piping.

Gas turbines are being developed and improved for use in the propulsion of ships and as prime movers for emergency generators. This will result in increased Navy demands for techniques and materials peculiar to gas turbine production.

The increasing size and weight of radar antenna to detect and track modern aircraft requires topside weight savings in our combatant ships to preserve their stability and keep them upright in a heavy sea or when they are damaged. One step to meet this need is a design trend to lighter structural ma-

Chart 4



terials for masts and deckhouses to compensate for the larger antenna.

Every effort is being made to utilize the experience of World War II in the standardization of highly repetitive equipment and machinery to facilitate and expedite production and at the same time to retain flexibility whereby design improvements can be readily absorbed in the mobilization plans.

In closing, I shall endeavor to summarize the over-all problem of shipbuilding production.

Chart 3, "Actual National Effort—World War II."—From 1941 to 1945 our total national effort, expressed in billions of dollars, doubled to provide the ships and arms needed to fight World War II. You will note that the effort on civilian goods and services remained substantially level on a dollar scale. At the same time military expenditures were climbing rapidly. The productive ceiling of the United States was not reached, but we approached it much more closely than in World War I.

Chart 4, "Required National Effort—World War III."—If World War III comes and lasts long enough, the annual productive output may reach a physical ceiling, by whatever dollar value it may be represented. Military expenditures must go from the present level of about 13 billion dollars annually to a mobilized level which in the chart is shown as a hypothetical almost 200 billion annually.

Chart 5

SHIPYARDS BUILDING—THEN AND NOW

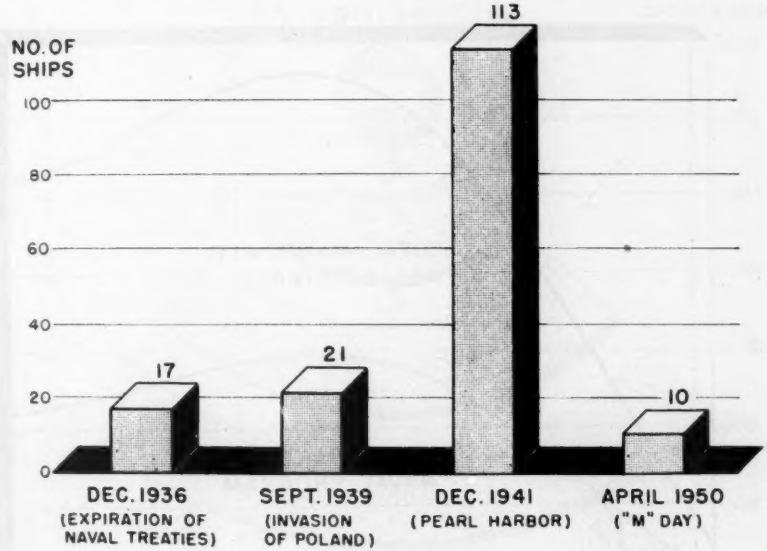
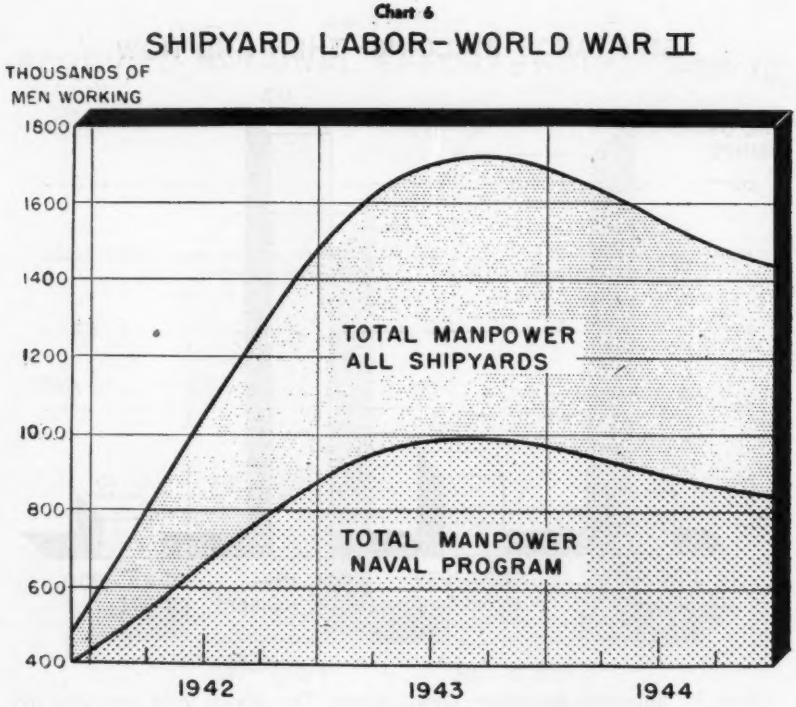


Chart 5, "Shipyards Building—Then and Now."—Contrasted to our position on D-day in December 1941, less than one-tenth of the shipyards are building naval vessels now than there were then. Of those shipyards still building, the average tonnage in each is considerably lower than the average tonnage per shipyard in 1941.

Chart 6, "Shipyard Labor—World War II."—Our real task in shipbuilding production is going to be the recruitment and training of shipyard labor. For two years before the Pearl Harbor attack, the shipbuilding industry had been augmenting its labor force at a net increase rate of about 20,000 men per month. By December 1941 employment in the industry had reached close to 600,000 men. After Pearl Harbor the rate of recruitment was stepped up to an average of 48,000 net gain per month. This proved to be somewhat too rapid for proper assimilation and training. However, it was done and the shipbuilding industry reached its peak of 1.75 million men in July 1943, 19 months after Pearl Harbor. It is probable that the recruitment rate of shipyard labor may have to be even greater than 48,000 per month unless something is done to expand the peacetime industry.

While shipyard manpower is climbing up to whatever is required in World War III, general industry must divert many thousands of men in support of the program. We see the task in the industries behind the shipyards as one of using presently employed labor in approximately the location it is now employed to turn out, in general, the same thing it is doing now but to Navy designs and specifications. Thus we visu-

Chart 6



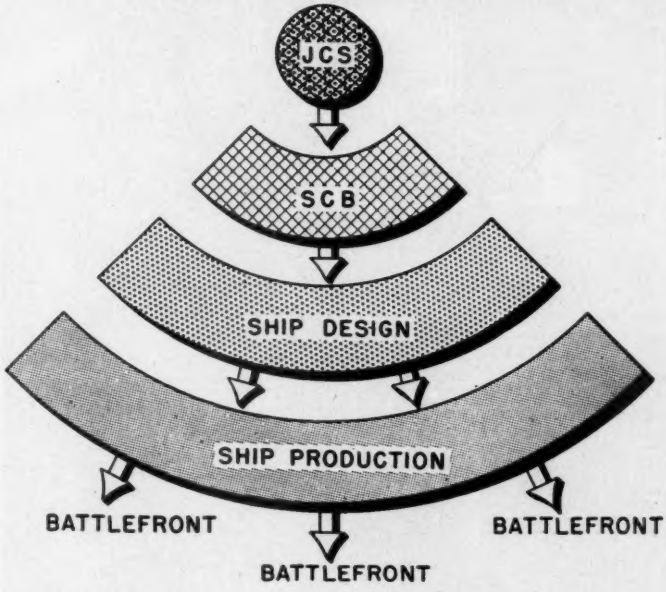
alize the shipbuilding industry's task as one of great expansion and general industry's task as one of fairly violent conversion.

In conclusion, I would like to nail to the masthead the importance of design and specification in planning shipbuilding production and in mobilizing rapidly to the required output. Several prototypes are under construction or conversion to develop and prove in service new designs and their components. Few of the studies are as glamorous as the guided-missile ship and the nuclear-powered submarine, but each contains thousands of design decisions which are profoundly important in the production of those ships in an emergency. The problem is to design the minimum amount of men, material, and facilities into the maximum amount of fighting power.

Chart 7, "From Ship Characteristics to Ship Design to Production."—If military armaments are considered to flow outward from the Joint Chiefs of Staff at the center to the battle fronts at the periphery, the progressively greater importance of each decision is visualized. Ship characteristics are shaped by a board under the Chief of Naval Operations, ship designs are delineated by a few hundred in the material bureaus of the Navy Department, and ships are built by thousands of men in general industry and shipyards. An ounce of design thought may save a ton of fabricated material on the shipbuilding ways.

Chart 7

FROM SHIP CHARACTERISTICS TO SHIP DESIGN TO PRODUCTION



JET PLANES SPOTTED ON CARRIER DECK

Official Department of Defense Photograph

COMMENTS ON SHIP PERFORMANCE

COMMANDER CHARLES H. MEIGS

THE AUTHOR

Graduated from the U.S. Naval Academy in the Class of 1937. After about three years at sea, ending as Chief Engineer of a destroyer, the U.S.S. *Ellet*, was selected for a post graduate course of instruction in Naval Construction and Engineering. Received Master of Science degree from Massachusetts Institute of Technology in 1943. Since then has served in the Boston Naval Shipyard, U.S.S. *Enterprise*, Design Division, Bureau of Ships and the Naval Boiler and Turbine Laboratory. During his tour of duty in the Bureau of Ships, Commander Meigs served as Assistant Secretary of the Society.

AUTHOR'S NOTE

These comments might be considered by some to take liberties with the truth. They are intended to correlate, in the simplest possible form, the principal factors which influence ship performance. Where many interrelated variables are involved it is difficult to decide which to neglect. Furthermore it is difficult to decide what assumptions are justified in the interest of simplicity. Those who desire further details and more exact information will find them in standard works such as those listed below which have been published by the American Society of Naval Architects and Marine Engineers:

"Speed and Power of Ships D. W. Taylor

"Marine Engineering" Seward

"Principals of Naval Architecture" Rossell and Chapman

If the following offends the sense of propriety of some design engineers the author requests their indulgence. If it is of assistance to some operating engineers it will have served its purpose.

The performance of individual ships is strongly influenced by conditions which are subject to considerable variation during an operating period of reasonable length. As a result comparison of the performance of sister ships, or of a particular ship at different times, frequently discloses differences which, unless carefully examined, may appear to be discrepancies. Naturally there are at times real discrepancies but more frequently the differences can be reconciled after analyzing the conditions under which the performance data were taken and determining the relationships that existed between the important variables affecting performance. To obtain an accurate interpretation of such information data operating personnel must take account of the variable conditions and factors influencing the performance data under consideration.

Because ship performance is strongly influenced by variable conditions great care must be exercised in making general statements regarding it. In fact, accurate statements of necessity must take account of these conditions and related variable factors and in so doing tend to lose their generality. This article will deal with the fundamental performance *criteria*—speed, propeller RPM, Shaft horsepower, and Fuel Consumption,—and the important variables influencing them. The relationships between the criteria will be expressed in terms of the usual *factors*. These factors are variable and are strongly influenced by variable *conditions* which are: displacement, bottom roughness, weather, (wind and sea), condition of propulsion machinery and operation of machinery. Variations in these conditions affect ship performance through their influence on individual factors in the relationships between criteria.

For the purpose of this article the following definitions apply.

Speed is the rate of motion of the vessel through the surrounding water. It is expressed in knots and may be determined by measuring the time required for the vessel to traverse a "measured mile." By making several runs in opposite directions the effect of current may be eliminated.

RPM is the rate of rotation of the propeller. It is expressed in revolutions per minute and determined by mechanical or electrical counters attached to the propeller shaft.

Shaft horsepower is the mechanical power delivered to the propeller by the propulsion shafting. It may be measured by a torsionmeter which determines torque. The combination of torque and RPM gives SHP. (For simplicity mechanical and other losses in propulsion shaft bearings, reduction gears and turbine bearings have been included with turbine internal losses. See Appendix.)

Fuel Consumption is the total fuel oil burned in boilers or diesel engines in a specified period. It is determined by measuring the oil supplied by means of a meter or measuring tank and may be stated in several ways, the more common being gallons per hour, pounds per hour, and pounds per shaft horsepower-hour.

Displacement is the weight of water displaced by the ship. It is expressed in tons (long) and is determined from the ships mean draft. It should be corrected for trim.

Bottom roughness is the condition of the surface of the ship's underwater body and is determined by the finish on painted surfaces and the size and shape of discontinuities and excrescences on the hull. It is expressed by a numerical roughness coefficient which can be calculated from trial data evaluated in conjunction with model tests.

Weather is the condition of wind and sea. Wind is expressed in knots relative to the ship and is determined by an anemometer and wind direction indicator. Sea (height of waves) is expressed in numerical units of an arbitrary scale and determined by "seaman's eye."

Condition of propulsion machinery refers to the material condition of machinery components. It is good, bad or indifferent depending upon the age of the equipment, the time it has been operated since overhaul, and the type of care it has received. It cannot be measured but can be estimated after studying the machinery history and examining the machinery.

Operation of machinery may be good, bad, or indifferent in proportion to the effort and knowledge brought to bear by operating personnel. It can not be measured but can be estimated by observing how closely operating conditions conform to optimum design conditions.

The two relationships between performance criteria which are of fundamental importance to operating engi-

neers are: speed-RPM and speed-fuel consumption. These two relationships are closely associated but will be discussed separately. Shaft horsepower is fundamental to both and neither can be discussed without reference to it. If shaft horsepower could be measured afloat as readily as can RPM it would doubtless be used in place of RPM. Designers use the speed-SHP and SHP-fuel consumption relationships more frequently than those previously mentioned and, as shown below, those involving SHP must be understood before intelligent use can be made of the speed-RPM and speed-fuel consumption relationships.

Let us consider first the speed-RPM and speed-SHP relationships, and examine the forces involved in the propulsion of a ship when the pertinent variable conditions (displacement, bottom roughness, weather) are constant. Under this condition there is, for each speed a specific value of hull resistance which must be overcome to move the ship. This resistance (R) is opposed by a force of equal magnitude which is the net thrust produced by the propeller in driving the ship. Actually the total propeller thrust (T) required is slightly greater than the resistance because in effect the propeller, by "sucking" water away from the stern, makes the ship a little harder to drive. The basic equation of the equilibrium of forces is

$$R = (1\text{-}t)\ T$$

Where t is an experimentally determined figure known as thrust deduction coefficient. It varies with propeller size and may vary with speed for a given ship. As is shown in the appendix thrust is commonly combined with speed (V) to obtain the effective horsepower (EHP) delivered *by* the propeller in producing the thrust required to drive the ship. In order that the propeller may deliver a given EHP a larger shaft horsepower (SHP) must be delivered *to* it by the propeller shaft. SHP is related to EHP by the propulsive coefficient (C_p) which is the product of hull efficiency, relative rotative efficiency and propeller efficiency and is always less than 1. C_p varies with hull and propeller design, loading, RPM, and operating condition but, for a given propeller on a given ship with the variable conditions constant, it varies only with speed. Thus for the ship and conditions under consideration

$$V = 325.5\frac{(C_p)\ (SHP)}{R} \ldots\ldots\ldots (A)$$

This is the speed-SHP relationship and shows that, for a given ship, speed is essentially determined by the ratio $\frac{SHP}{R}$ but is influenced by the propulsive coefficient.

The speed-RPM relationship is determined by the characteristics of the propeller. Propeller performance is expressed in terms of propeller coefficients which are determined by tests. By relating propeller torque to SHP in equation (A) the speed-RPM relationship may be obtained. In order to do this the torque coefficient of the propeller (C_q) must be employed. Using C_q the propeller torque may be expressed in terms associated with the propeller which are RPM, pitch and diameter. The propeller torque must equal the torque delivered to the propeller by the shaft which is expressed in terms of RPM and SHP. From this is obtained the speed-RPM relationship which is given as formula (B) in the appendix. For a ship with a given propeller, pitch and diameter are constant, hence (B) is reduced to:

$$V = (\text{constant})\ (C_p)\ (C_q)\frac{N^3}{R} \ldots (b)$$

This is the speed-RPM relationship. It shows that the speed is essentially determined by the ratio $\frac{N^3}{R}$ but is influenced by the propulsive coefficient and torque coefficient which vary with operating conditions.

Formulae (A) and (b) show how important resistance and propeller perform-

ance are to ship performance. The effect on these of changes in the variable conditions is complicated. Variation in one condition (displacement, bottom roughness, weather) entails variation of one or more of the variable factors in the equations. If one factor is altered others must readjust themselves to maintain the equilibrium of forces acting on the ship. This may be shown by taking a hypothetical case in which it is assumed that displacement can be instantaneously increased. Consider a ship that is moving at a given speed. If displacement is instantaneously increased, all other variable conditions being unchanged, a chain of readjustments will occur. Because the resistance at the given speed is greater with the greater displacement the ship will slow down. As it slows down the thrust increases, (throttle setting unchanged) and as a result RPM decreases. The ship will slow down until the net thrust, which is increasing, balances the resistance, which is decreasing. When equilibrium is established the thrust (and resistance) will be greater but the speed less than was the case at the lighter displacement. Since the throttle setting is the same SHP will be the same, RPM reduction being balanced by torque increase. To the extent that the change in propeller loading affects the propulsive coefficient, EHP will be altered. This in turn will determine the speed at which equilibrium is established. If higher loading of the propeller reduces the propulsive coefficient EHP will decrease and the product of (R) (V) must decrease. If the propulsive coefficient is unchanged EHP will be the same and the product (R) (V) the same, with R greater and V smaller than they were at the lighter displacement.

An increase in bottom roughness or adverse weather will increase resistance for a given speed and a similar sequence of adjustments will occur. From the above it is apparent that performance data obtained from a specific ship on two different occasions cannot accurately be compared unless corrections are made for differences in displacement, bottom roughness, or weather. These corrections are difficult to make accurately. Furthermore, performance data are frequently subject to errors of personnel or inaccuracy of equipment used in obtaining it. Naturally these errors are not the same on different occasions.

The differences in speed-RPM and speed-Shaft horsepower relationships occasioned by ordinary variation in displacement, bottom roughness, or weather are not small. If the displacement of a destroyer is increased 10% (300 tons) the SHP required for a given speed will be increased about 10% at cruising speeds and about 12% at high speeds. If the displacement of a large carrier is increased 5% (3000 tons) the SHP required for a given speed will be increased about 10% at cruising speeds and about 12% at high speeds. If the displacement of a large carrier is increased 5% (3000 tons) the SHP required for a given speed will be increased about 5%. The RPM will be increased between 2 and 3%.

The effect of fouling on ship's hulls is well known. Marine growth attached to the hull so increases skin friction that the hulls resistance at a particular speed is increased; the increase being proportional to the amount of growth. In addition to fouling the type of paint used on a ship bottom and the condition of this paint have an important effect on resistance. One who has examined the surface of paint on a ship bottom knows that plastic paints look and feel rougher than the thinner resinous paints. Furthermore, paint applied carelessly often presents an irregular or lumpy surface which will materially increase friction. It is quite possible that a rough paint, carefully applied, may so increase the ship's resistance that at high speeds the power required to drive the ship may be as much as 20% more than would be necessary to drive the ship with its bot-

tom covered by a carefully applied coat of the smoothest standard paint available.

Rough water and high winds will increase resistance by as much as 10%. Any change in the condition of the weather or in the material condition of the underwater body or propellers will alter the relationships existing in equations (A) and (b) before the change occurred. For this reason speed-RPM tables and speed-SHP curves are only representative of a true relationship under one specific set of circumstances. This set of circumstances is duplicated during the life of a ship relatively infrequently and then only by coincidence. It can be approximated if operating personnel desire but cannot be duplicated at will.

Consider now the speed-fuel consumption and SHP-fuel consumption relationships. Since fuel consumption is more directly associated with SHP the SHP-fuel consumption relationship is a better index of engineering performance. For the reason previously stated, that SHP is not measured in normal operation, the speed-fuel consumption relationship is more commonly used by operating engineers. The fuel consumed is primarily determined by the speed of a ship or, more accurately, by the power which must be developed to make this speed. The power or heat required for auxiliary equipment such as pumps and blowers, space heating, galley, electric load, evaporators and fuel oil heating also influences fuel consumption. In addition the material condition and operation (good or bad) of major machinery components and the number of these units in operation exerts an important influence. Of these boiler operation is the most important.

Neglecting the effect of auxiliary equipment which, except for main propulsion auxiliaries (pumps and blowers), may be assumed to be independent of propulsive power developed, let us develop the relationships between speed and fuel consumption and between SHP and fuel consumption, assuming that the fuel consumed depends upon propulsive power output alone. In a turbine-driven vessel the SHP is the useful energy output from the turbine. The turbine converts heat energy in the steam to mechanical energy at the turbine coupling. The energy converted is the product of steam flow and the difference between the energy in the steam introduced at the throttle and the energy of the steam exhausted from the turbine. The useful energy output is the difference between the total energy converted and the mechanical losses and is expressed by

$$SHP = .000393\ (W)\ (H)\ (E) \ldots . (C)$$

The product of (H) (E) is the useful work obtained from the turbine in btu per pound of steam flow. H varies with initial and final steam conditions, that is, with throttle pressure and temperature and condenser vacuum. Steam flow (W) is determined by throttle setting and influenced by initial pressure. Overall efficiency (E) is a characteristic inherent in the propulsion machinery and, for a given power output, does not vary within significant limits as long as the RPM-SHP relationship at that power is not materially altered.

If the steam required for loads other than propulsion is neglected SHP may easily be related to fuel consumed. This relationship is:

$$SHP = 7.269\,\frac{(F)\ (B)\ (H)\ (E)}{M} \ldots (D)$$

In this equation the overall efficiency (E) varies with RPM. In high speed ships it is low at 10 knots, rises rapidly between 10 and 20 knots and above 20 knots rises slowly until about 30 knots, then decreases slightly between 30 knots and full power. Boiler efficiency (B) varies over a fairly wide range depending upon combustion rate (oil fired), condition of the boilers and the way the boilers are operated. Overall efficiency (E) is not greatly affected by operating

methods but boiler efficiency is quite sensitive to them. The number of boilers in operation at a given speed affects combustion rate and, if blowers are not properly operated, the boiler efficiency may be reduced either by excess air or insufficient air.

Finally, the speed-fuel consumption relationship, which is determined by combining formulaes (A) and (D), is:

$$F = .000422 \frac{(R)\ (M)\ (V)}{(C_p)\ (B)\ (H)\ (E)} \ldots (E)$$

Changes in any one of the following variable conditions will require a readjustment of the variable factors in the equation to maintain equilibrium.

Displacement .....affects R and C_p
Bottom roughness .....affects R and C_p
Weather .....affects R and C_p

Operating conditions
- Feed temperature .....affects M and B
- Initial steam temperature .....affects M and H
- Initial steam pressure .....affects M and H
- Condenser vacuum .....affects H and E
- Boiler operation .....affects B

Condition of machinery
- Boiler cleanliness .....affects B
- Turbine condition .....affects E
- Type of propeller installed.....affects C_p

For example: if feed temperature is allowed to decrease M will increase and B will decrease. If oil fired (F) remains constant V (and R) will decrease until the product of (R) (V), being less, offsets the increase in $\frac{M.}{B}$ For the small change in speed (and RPM) C_p, H, and E will be virtually unchanged.

For diesel engines it can be shown that a similar list of variables influences the speed-fuel consumption ratio. These variables are: displacement, bottom roughness, weather, propeller type, engine operation, mean effective pressure, engine condition and heating value of fuel. For vessels having electric drive the relationships between speed and fuel consumed and between SHP and fuel consumed are considerably more complicated because the ratio between propeller RPM and the speed of the prime mover (turbine or engine) is not fixed as it is with geared drive or direct drive. This flexibility strongly influences the efficiency of the propeller and the prime mover. In addition, the performance of the electrical machinery varies with speed and load, thus introducing a new group of variables which must be added to those already mentioned in the previous two paragraphs.

In addition to the factors mentioned above, which are related to propulsion machinery primarily, the speed-fuel consumption ratio is influenced by the auxiliary equipment in operation. If the influence of this equipment is not neglected, as it was in developing equations (D) and (E), additional factors enter into the relationship, some affecting the amount of steam generated (W), which influences fuel consumed indirectly, and others, such as diesel generators, affecting fuel consumed directly. It is important to bear in mind, however, that in normal combatant vessels at powers above 20% of full power, all auxiliary equipment uses less than 10% of

the total energy obtained from combustion of the fuel. Thus great improvement in the performance of auxiliaries has a very small affect on total fuel consumption. At low speeds, where less than 15% of full power is required. the influence of auxiliaries on total fuel consumed is much greater, auxiliaries absorbing almost half the total energy at about 5% of full power.

The foregoing shows that speed-fuel consumption tables or curves are representative of true relationships only under one unique set of circumstances which it is absolutely impossible to duplicate at will.

One or more ships of each type or class are usually given underway trials at the end of the building period. During these trials the operating characteristics of the ships are compared with the design characteristics and performance data are obtained for the guidance of operating personnel. During trials many runs may be made for various special purposes but those for standardization and fuel economy are generally the most important. Standardization trials consist of runs at several speeds over a measured mile course at two displacements. Speed, RPM, SHP, draft(displacement) are accurately measured and recorded. The data are plotted in curves of RPM vs Speed and SHP vs Speed for each displacement. Occasionally thrust is measured by means of thrustmeters installed in the main thrust bearing. Where thrust is measured resistance may be more accurately determined. Fuel economy trials consist of steady state runs of about two hours duration at several speeds. Fuel consumption and SHP are accurately measured and recorded. Usually important performance data are obtained on components of the engineering plant so that a heat balance may be prepared to check design calculations. Fuel economy data are plotted in various ways, the more common being curves of fuel consumption vs. speed, fuel consumption vs. SHP, specific fuel consumption (lb/SHP hr) vs. speed, and fuel consumptions vs. miles steamed at several speeds.

Trials are usually conducted under favorable weather conditions, with new bottom paint and machinery in good condition. Specially trained operating crews are frequently used to obtain optimum operation. Sometimes it is not possible to conduct trials at displacements that are encountered in normal service. For these reasons trial performance curves tend to be representative of optimum, if not abnormal, operating conditions.

In comparing the performance of individual ships with either published performance information or data obtained on similar vessels during normal operation, careful thought should be given to the conditions under which the data being compared were obtained and no final conclusions drawn until allowance has been made for differences in the variable factors. Since expression of these differences in numerical values is difficult and often impossible, evaluation of service performance using the averages obtained from a number of runs under nearly similar conditions is generally sounder than where data obtained from one short run are used.

Appendix

SYMBOLS

R = resistance in lbs
t = thrust-deduction coefficient
T = thrust in lbs
EHP = effective horsepower
V = speed in knots
C_p = propulsive coefficient
SHP = shaft horsepower delivered to propeller
Q = propeller torque in lb/ft
C_q = propeller torque coefficient (RPM, loading)
p = propeller pitch in ft.
d = propelelr diameter in ft.
N = RPM
W = Steam flow through turbine throttle run lb/hr
H = Isentropic heat drop in turbine i.e., $h_1 - h_2$ where
h_1 = enthalpy at throttle pressure and temperature and
h_2 = enthalpy at exhaust pressure with entropy same as at throttle
E = Overall efficiency of turbine, gears and shafting. This is the product of turbine engine efficiency, and the mechanical efficiency of turbine, gears and shafting. (decimal)
F = fuel burned in lb/hr
B = boiler efficiency in decimals
M = heat absorbed by water and steam in passing from economizer inlet to superheater outlet (btu/lb)

DEVELOPMENT OF FORMULAS

$R = (1\text{-}t)T$ .....Ref(1)—p 143
$EHP = .00307\ R\ V$.....(1)—p 109

Substituting:

$EHP = .00307\ (1\text{-}t)\ T\ V$
$EHP = C_p\ SHP$ .....(2)—p 23

Substituting:

$$V = 325.5\ C_p \frac{SHP}{R} \quad \text{.....(A)}$$

$Q = C_q N^2 P^3 d^2$.....(1)—p 141

$$Q = \frac{33000\ SHP}{2\ N}$$

Equating and transposing:

$SHP = .000189\ C_q N^3 P^3 d^2$

Substituting in (A):

$$V = .0615\, C_p\, C_q \frac{N^3 P^3 d^2}{R} \quad \ldots\ldots\ldots\ldots\ldots (B)$$

$$\frac{W}{SHP} = \frac{2544}{H\ E} \qquad (3)—p\ 8\text{-}57$$

$$SHP = \frac{778}{(33000)\ (60)}\ W\ H\ E = .000393\ W\ H\ E \ldots (C)$$

From boiler heat balance (assuming heating value of fuel is 18500 btu/lb)

$$18500\ F\ B = W\ M \ldots\ldots\ldots\ldots\ldots\ldots (3)—p\ 7\text{-}12$$

Transposing and substituting in (C):

$$SHP = 7.269\ \frac{F\ B\ H\ E}{M} \quad \ldots\ldots\ldots\ldots\ldots (D)$$

Combining (D) with (A):

$$V = 2369.76\ \frac{C_p\ F\ B\ H\ E}{R\ M}$$

or: transposing,

$$F = .000422\ \frac{R\ M\ V}{C_p\ B\ H\ E} \quad \ldots\ldots\ldots\ldots\ldots (E)$$

References

1. "Principles of Naval Architecture." Rossell and Chapman, Vol. II.
2. "Marine Engineering." Seward, Vol. I.
3. "Mechanical Engineers Handbook." Kent (1950), Vol. II.

MARINE PILOT OPERATES ARMY PLANE ABOARD NAVY CARRIER

Official U. S. Navy Photograph

SOME USES OF RUBBER IN NAVAL VESSELS

T. A. WERKENTHIN, E. A. BUKZIN, E. F. GREENLEAF, E. LEVENE

THE AUTHORS

THEODORE A. WERKENTHIN is Principal Materials Engineer, Civilian-in-Charge of the Rubber Branch, Bureau of Ships, Navy Department, Washington, D. C. He is charged with research, development, specification writing, and all other phases of work with rubber, synthetic rubber, and plastic elastomers. Mr. Werkenthin received his B.A. degree in 1921 and M.A. in 1923 from the University of Texas. He also did post-graduate work on his Doctorate at Texas University in 1924 and again in 1935 on various hydrocarbon polymers and resins derived from petroleum. He taught both organic and inorganic chemistry at his Alma Mater; at Taylor University, Upland, Indiana, as Head of the Chemistry Department, and at Queens College, Charlotte, N. C., also as Head of the Chemistry Department.

Mr. Werkenthin's industrial experience was gained with the Solar Refining Company, Lima, Ohio, as Research Chemist; as Plant Engineer with the White Eagle (Socony) Refining Co., Augusta, Kansas; as Technical Superintendent with the Grayburg Oil Corporation, San Antonio, Texas; and as Assistant Chief Chemist with the Deep Rock Oil Corp., Cushing, Oklahoma. During his six years with the latter concern he became interested in rubber manufacture and research in connection with improvement of packing and gaskets, gasoline and oil hose, drilling equipment and rubber solvents and diluents made from petroleum.

He became associated with the Navy in 1937. His dual experience with petroleum and rubber proved of value during the period when the country had to look to petroleum for most of its synthetic rubber. He is credited with building up the rubber interests of the Bureau of Ships since 1937 so that it now includes four rubber manufacturing shops, and eight laboratories equipped for rubber testing, compounding, development and research. Numerous patents and technical publications attest to the importance of this work to the rubber industry.

Mr. Werkenthin is a member of the American Society of Naval Engineers, the Society of Sigma Xi, and Phi Lambda Epsilon honorary Chemistry Society. He is active in the Rubber Division of the American Chemical Society and the American Society for Testing Materials, being a member of A.S.T.M. Committee D-11.

He is the founder and past president of the Washington Rubber Group.

MR. ELLIOTT A. BUKZIN received his Bachelor's degree in Chemical Engineering from the College of Engineering of New York University in 1939. He was employed as an illumination engineer in New York during 1940 before coming to Washington, D.C. After obtaining sufficient graduate credits in Naval Architecture, he came to work for the Bureau of Ships in May 1941 in that capacity. In August 1943, he transferred to the Rubber Branch of the Research and Development Division where he is presently employed as a Senior Materials Engineer. He was elected Treasurer of the Washington Rubber Group, an affiliate of the American Chemical Society, for the year commencing September 1949.

MR. ELMER F. GREENLEAF received his Bachelor's degree in Chemical Engineering from Massachusetts Institute of Technology. Since graduation, he has been employed by private industry from 1941 to 1948, with the exception of the period from 1942 to 1945 when he worked at the Chemical Warfare Center. His four years in industry were exclusively devoted to rubber work, culminating in 1948 as factory superintendent. In December of 1948, he joined the Rubber Branch of the Bureau of Ships where he is a Materials Engineer. He is a member of the American Chemical Society and the Washington Rubber Group.

ETHEL LEVENE graduated from Brown University, having majored in mathematics. Following graduation, she held administrative positions in industrial concerns until she entered government service in 1942. After working in Soils Laboratories for the War Department, she joined the Rubber Branch in the Bureau of Ships in 1944, where she is a Materials Engineer. In this position, she handles research and development work on gaskets, packings, cellular rubber, protective clothing, safety equipment, and footwear, and also prepares specifications covering these and allied end-products. Since its inception in 1948, she has been Recording Secretary for the Washington Rubber Group and will act as Chairman of the Women's Committee for the February meeting of the Division of Rubber Chemistry of the American Chemical Society.

It seems that ever since Pearl Harbor, the country's interest in rubber has been so great and so much information and misinformation has appeared in books, magazines, and newspapers about rubber, that practically everybody has some knowledge of this extremely important raw material. This discussion will be limited to the use of rubber in Naval vessels. In considering the use of rubber on Naval vessels, we will discuss the use of rubber on all sizes of ships from large battleships, down to life boats and even inflated rubber craft. Without the thousands of rubber items used in its construction, and in its equipment, the modern fighting vessel could not operate. It has been estimated, for example, that in carriers of the Midway class, over 60,000 pounds of rubber is used.

As long as we were limited to the use of natural rubber, the diversity of compounds was not nearly as great as it is today with the availability of so many different synthetic rubbers and dozens of variations which can be made of each of these polymers by variation of the percentages of the individual co-polymers as for example, the well known general purpose rubber composed of roughly 70% Butadiene and 30% Styrene known as G.R.S.

Beyond saying that the average rubber compound may have as many as twenty or more ingredients, each of which contributes to the specific properties of the rubber, we will not be in a position in this short discussion to delve into the intricacies of rubber compounding. Suffice to say that many of the larger rubber companies have on file working formulations which number between six and eight thousand. In addition to that, there are experimental and little used formulations which may number three or four thousand more. Rub-

ber appears in a great many different conditions, types and classes, as soft as velvet and as hard as limestones.

It is extremely important that the naval and other interested personnel have some general idea of the diversity of rubber products used. It is also extremely important that we all have some general conception of the strong points and the weaknesses of rubber compounds.

Unusual care must be exercised in selecting shipboard rubber materials because unlike landborne equipment, we cannot drive into a garage or service station in the middle of an ocean to replace rubber items, especially those normally submerged or inaccessible except during docking operations. We cannot, for example, change the rubber shaft covering or replace water lubricated rubber bearing strips during a cruise. Also the combination of sunshine, salt spray and air is extremely destructive to many materials.

Ships personnel and other personnel within and outside the Bureau of Ships can help to improve the quality and effectiveness of rubber aboard ship by special reports and by docking reports in which rubber items are mentioned. Information on service life and satisfactoriness of rubber integral or component parts and rubber auxiliary equipment comes regularly to the Bureau from experienced laboratory personnel who visit ships while they are being docked in the Navy Yards, San Francisco, Mare Island, Puget Sound, Portsmouth, New York and Philadelphia. Only by extending this source of information can we expect to constantly improve rubber.

In considering the use of rubber on board ship, it may be well to do this by working from the outside hull, inward to the machinery and living spaces of the ship.

In the category of hull uses of rubber, we may mention the coatings of the rudder, strut, shaft and other underwater exposed surfaces. Coatings have been provided for sea chests, i.e., the many water intake and exhaust connections.

UNDERWATER RUBBER COATINGS AND PROTECTIVE COVERINGS

There are several anticorrosive-anticavitative types that may be used here. For instance, there are the flame-sprayed Polysulfide synthetic rubber coatings which are supplied in powder form and which are applied through a flame similar to gas welding flame which softens the powder almost to the molten state and which when impinged on a warm metal surface such as a rudder, propeller or a propeller strut, solidifies and forms a rubber-like coating. For example, in Figure 1 is shown a large test panel being flame sprayed with experimental polysulfide synthetic rubber coatings. It is as a result of such comprehensive experimental work that extensive improvements have been made in the adhesion and in the resistance of this coating to cavitation and corrosion. The earlier types of flame sprayed coatings were horn-like and had very little

FIG. 1—Shows a large test panel being flame sprayed with an experimental polysulfide coating to simulate actual service conditions.

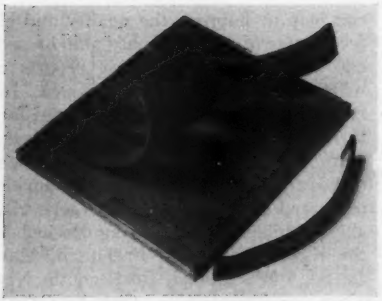


FIG. 2—Shows a test slab sprayed with polysulphide from which strips have been cut to determine adhesion.

flexibility, whereas the newer types of coatings are truly rubber-like in appearance and are quite flexible. In Figure 2 is shown a panel of flame sprayed coatings which have been sliced into strips in order to determine the adhesion between the metal and the rubber.

A successful rubber application of many years standing is the rubber coating of the main propulsion shaft. At first, the coating of the main propulsion shaft was limited to that portion of the shaft which is within the stern tube, because this portion of the shaft could not be inspected during docking until the shaft was pulled. However, due to the excellent results obtained with these rubber coatings, rubber coating was recently extended to the tail shaft as well. Rubber coating of shafting has a rather interesting history. Insofar as the Bureau of Ships' records indicate, the rubber coating of shafting was first observed on the German liner, the *Leviathan* which was taken over in World War I. When the ship was being altered for troop-carrying service the rubber covering was discovered. One of the rubber companies was asked to determine whether it could repair the slight damage which had occurred in the rubber covering. Not only did our American manufacturer repair the German coating, but it continued to improve the coating in collaboration with the Navy. The main improvement was with respect to the degree of adhesion obtained between the rubber and metal. A combination hard rubber under-layer and softer rubber covering was developed which has shown service life of 20 years and longer. This type of coating is shown in Figures 3 and 4 respectively, where a rubber sheet is shown being wrapped around the steel shaft which is held in a lathe. The coating is generally done in two layers in order to insure complete, water-tight integrity of the coating. After the wrapping is complete, steam is applied to the inside

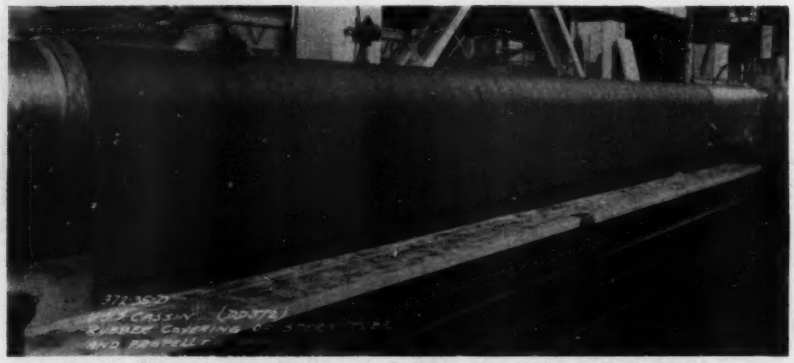


FIG. 3—Shows a large destroyer shaft being coated with a sheet of rubber.

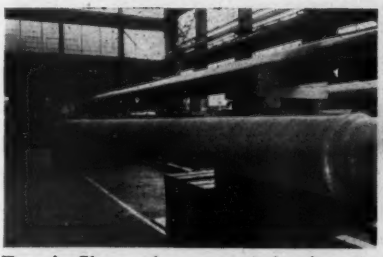


FIG. 4—Shows the same shaft after the rubber has been vulcanized in place.

of the hollow shaft for several hours until complete vulcanization occurs. For the large combatant ships, this hard rubber coating is used exclusively because it has exceedingly strong mechanical and chemical adhesion to the metal and is protected from scuffing by a soft rubber outer layer. This type of rubber shaft covering has been in use for over 30 years and has been found to give exceedingly thorough protection to the shaft from corrosion. Since it has not been found practical to do a sheet vulcanizing job in dry dock, considerable experimentation has been carried out with other types of coatings. Since flame sprayed coating and some chloroprene-type coatings can be applied in dry dock, they offer an advantage over sheet rubber vulcanized coatings. The chloroprene, acrylicnitrile organasol, as well as coated liquid polymer polysulfide types of coatings can all be applied in dry dock. The liquid polymer Polysulfide-type of coating is cured under atmospheric conditions in the summer time merely by the addition of an accelerator just prior to application. Increased acceleration in the rate of cure can be obtained by the use of either hot air or infra-red heating.

Similar types of coatings have also shown promise in reducing corrosion of fuel tanks particularly when used for Diesel oil or gasoline tankers. Ordinarily such tankers required complete overhauls and replacement of bulkheads within 5 to 7 years due to heavy corrosion and sludge formation in the cargo tanks. On the other hand, when these tanks are protected with these newer developed coatings, the tanks will merely require cleaning and no structural overhaul. Furthermore, the problem of making such tanks gas-free and explosion-proof when emptied, is greatly simplified. There are three coating systems under actual service evaluation at present. They are—(1) Polyvinylidine-chloride multiple coat system, (2) Polyvinylchloride system and (3) Polyvinylchloride reverse phase system. Coatings laid down from liquid rubber and synthetic rubber cements are often quite similar in their properties to some of the coatings applied in sheet form. These coatings serve an important part in the fabrication of rubber items as well as in their assembly with metals, woods, fabrics and other materials. So-called "cold" cement fabrication will yield adhesions of 100 pounds per square inch. On the other hand, fabrication with "hot" cements which are cured or vulcanized with rubber in a mold or under pressure will have adhesions in excess of 500 pounds per square inch.

One important application where the adhesion between rubber and metal is important is in the preparation of water lubricated rubber bearing strips which are exclusively used in the main propulsion bearing. Formerly, the bearing strips were made of natural rubber compounds and had a tendency of showing blisters after having been used in the main propulsion bearings. Natural rubber was replaced by Butadieneacrylicnitrile-type bearings which have shown no blistering or blowout tendencies even under extremely severe experimental conditions of pressure and temperature. The conversion from natural rubber to synthetic rubber was done as a conservation matter, but it proved to be extremely beneficial from the technical standpoint. The U. S. Naval Engineering Experiment station uses a 14″ bearing test machine installation in which all service conditions can be duplicated.

Since in a short time all extremely severe conditions can be run the gamut, the machine quickly evaluates experimental rubber compounds. Variations are made by raising or lowering the temperature by controlling the cooling water, the bearing pressure, and the loading. Simulated service tests have been correlated very closely with service conditions so that new experimental types of bearing strips may be readily evaluated to determine any technical advances made by the manufacturers supplying the water lubricated bearing strips. One of the differences in the behavior of natural rubber and synthetic rubber is shown in Figure 5 in which the natural rubber is beginning to show signs of blow-out damage whereas the synthetic rubber is completely uninjured. Actually the synthetic acrylicnitrile rubber bearing is many times more serviceable than the best natural rubber.

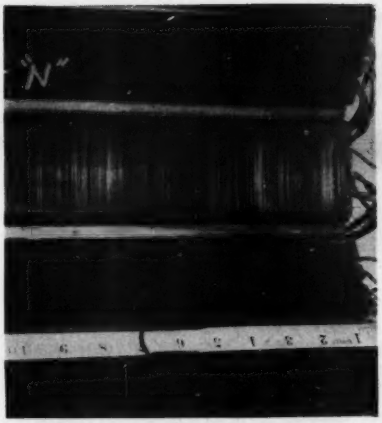


FIG. 5—Shows a blistered natural rubber bearing strip compared to the uninjured Butadiene-acrylic nitrile type rubber strip.

OTHER HULL APPLICATIONS

Among other uses are the Grommets and sheaths for aerials, water-tight cable fittings through the hull, for searchlights, radio, radar, signal lights. Another important use of rubber is matting for high voltage equipment used for the protection of personnel. Rubber or synthetic rubber matting for vibration absorption is used to reduce the fatigue of personnel in watch standing. This is particularly applicable to personnel standing in or near the engine room where they are subjected to vibrating machinery. It has been found that the use of the rubber matting greatly decreases their fatigue and increases their alertness.

Permanently adhered vulcanized rubber lining is used for wet spaces, such as heads, washrooms, and laundries. Slip-proof deckings are provided to permit sure footing even when decks are awash. Static dissipating or conductive matting or flooring is applied in powder

FIG. 6—Shows synthetic rubber matting of various types after being subjected to a fire retardancy test determination.

rooms, ammunition spaces, etc., to prevent sparks and possible explosions.

The experience of World War II demonstrated that one of the most important requirements of all materials aboard ship is that they show extremely good fire retardant characteristics. The basic difficulty is that any improvement in fire retardant characteristics generally means a concomitant lowering of the electrical properties. However, it has been found possible to develop rubber matting which is satisfactory in both respects. For example, in Figure 6 are shown various rubber matting strips after having been subjected to a fire test. Prior to World War II, a rubber latex hydraulic cement type of decking was extensively used. Due to the rubber shortage resulting from the capture of the Far East sources of natural rubber by the Japanese, it was found necessary to develop a slip-proof thin film decking which required no rubber constitutents.

DECK CAULKING

Seams of wooden decks have for years been caulked with Marine glue, a type of asphalt compound, applied over oakum or cotton which has been forced into the V-shaped groove formed by cutting a bevel in the planks. Wartime shortages forced a change from teak decks to ones made from domestic woods. Marine glue proved even more unsatisfactory in maintaining tight seams with the domestic wood used than it did when used with teak. New caulking compounds have been developed by industry. These compounds are polysulfide polymers in which the vulcanizing accelerator is added just before use. The liquid polymer coatings have the advantage of being much easier to apply, since no laborious preliminary caulking with oakum or cotton wick is necessary. While the liquid polymer caulking has the disadvantage of much greater material cost, it has much better adhesion to wood and much better flexing properties initially and excellent stability under wide temperature changes. Early liquid polymer compounds tended to bubble and soften at high temperatures, and to shrink or crack at low temperatures. However, presently available materials are much improved, and should be adequate for all service requirements. Marine glue has been a source of trouble, being soft and gooey in summer and brittle in winter. Most important of all, it has been found that synthetic rubber caulking used for caulking wooden flight decks, have shown remarkable resistance to the impingement of flames issuing from jet fighter planes. The ordinary Marine glue is melted and blown out whenever the jet plane exhaust impinges on the flight deck. It has been found possible to apply liquid polysulfide polymer caulking material by using high pressure grease guns. Since the use of rubber caulking material obviates the use of oakum or cotton wicking, a somewhat different bevel has to be cut in the wood.

GASKETS FOR DOORS AND HATCHES

An extremely important application of rubber is the use of gaskets for air and water-tight doors and hatches. The use of synthetic rubber and the development of special weather resistant rubber formulations have resulted in a greatly increased life of those rubber gasketing materials which are subjected to the action of light, ozone and general weather exposure. Certain technically trained laboratory personnel periodically board vessels whenever they come to Mare Island, Puget Sound, Portsmouth and New York Naval Shipyards for repairs or refueling. An interesting though extremely annoying phenomena is the continued appearance of natural rubber gaskets even though the applicable speci-

fications have specifically prohibited the use of natural rubber for a period in excess of 7 years. It is hoped that in the future, there will be strict adherence to the procurement of specification material. Procurement of synthetic rubber material will increase life expectancy of gaskets even further. The problem of developing satisfactory water and weather-tight gaskets is an extremely complicated one; especially so since requirements of the Forces Afloat have been set up that the gaskets must show satisfactory performance at —35°F.

Under subzero conditions such as are encountered in Arctic or Antarctic operations, ordinary rubber products exhibit many changes in their physical characteristics which may completely destroy their usefulness or serviceability. Most rubber compounds harden with lowering temperatures, become brittle, lose resilience, shrink and, in the case of gaskets, will show poor sealing results.

All presently known rubber-like polymers exhibit these thermal effects to a greater or lesser degree. Natural rubber undergoes crystallization at approximately minus 10°F, while chloroprene in the ordinary forms begins to crystallize at plus 32°F. Butadiene-Styrene synthetic (General Purpose) rubber, does not crystallize, but loses some of its desirable properties around minus 45°F. Oil-resistant nitrile rubbers also do not crystallize, but usually become hard and brittle at plus 10°F. The freezing point is lowered as the acrylonitrile content of the co-polymer is decreased. Considered particularly from the standpoint of resistance to weather and sunlight, chloroprene gaskets are undoubtedly superior to those of other synthetic or of natural rubber. However, chloroprene has extremely poor properties after long period exposure to low temperature since it has the characteristic of crystallizing. It has been necessary to develop gaskets which have a low modulus and, therefore, require low deflecting pressure. At the same time, the gaskets must show

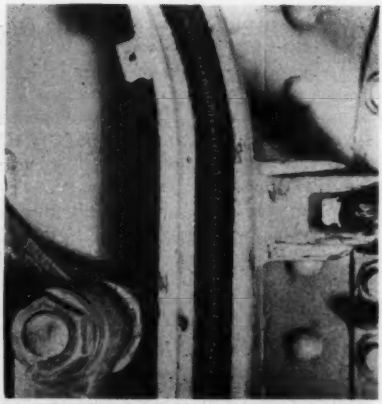


FIG. 7—Weather-tight door gasket showing severe ozone cracking and crazing.

resilience even under low temperature conditions and must not assume permanent set or deformation after having been indented by the "knife-edge" of the door. A severe condition of crazing and cracking is shown in Figure 7. By comparison a chloroprene gasket shows very little cracking and crazing (Figure 8). In Figure 9 is shown a gasket which has taken such a severe set or permanent deformation that it would probably not be air-tight or even-water-tight. Figure 10 shows an experimental natural rubber gasket with a 1/16-inch chloroprene veneer after a two-year weather exposure. There is an assembly of water-tight doors mounted on the roof of the Rubber Laboratory at the Mare Island Naval Shipyard which is used for simulated service tests. As a result of an extensive program, we are in a position now to procure water-tight and air-tight gaskets which are satisfactory at temperatures as low as minus 35°F. It has been found that for gasket materials to show satisfactory performance at low temperatures, they must not show extensive compression set after long periods of deflection but primarily must show rapid recovery after release of load even though still

FIG. 8—Weather-tight door showing a chloroprene gasket after exposure of two years with practically no cracking.

subjected to low temperature. When it was discovered that harder rubbers would show comparatively more satisfactory sealing characteristics than softer rubbers, it was found necessary to establish the "limiting hardness" of gaskets. This limit is carefully established by determining the maximum gasket hardness at which the aluminum doors will not distort, and simultaneously will not require excessive closing pressure.

The torque required to produce a 1/8-inch indentation of the scuttle coaming into the various rubber gasket materials was found to range between 20 and 44 foot-pounds. Hand loading tests on the scuttle indicated that it was possible for operators to exert torque values from a satisfactory minimum of 25 foot-pounds with an overhead mounting to a maximum of 120 foot-pounds for the low mounting. It was found that the scuttle could be just sealed from leakage against a hydrostatic pressure of 15 psi at minimum torques ranging all the way from 3 to 10 foot-pounds for the various gas-

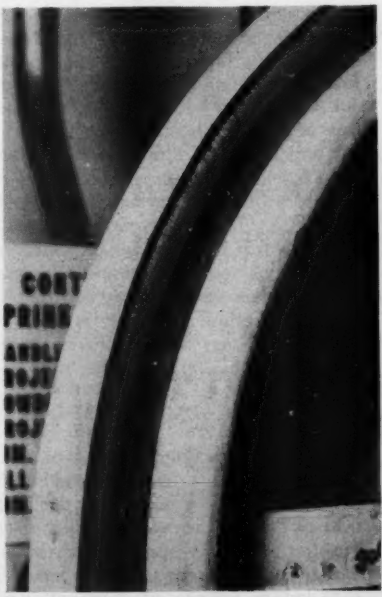


FIG. 9—Water-tight door gasket showing severe grooving.

FIG. 10—Shows an experimental natural rubber gasket with a 1/16" chloroprene veneer after a two year weather exposure.

TABLE A

EFFECT OF CONDITIONING TEMPERATURE ON SHORE TYPE "A" DUROMETER HARDNESS OF VARIOUS ELASTOMERS

CONDITIONING TEMPERATURE, DEG. F (CONDITIONING TIME - 1 HR.)

Type of Polymer	Stock No.		75			40			80 Instrument deflection, points			0			-20			-35		
			Initial	After 15 Sec.	Diff.	Initial	After 15 Sec.	Diff.	Initial	After 15 sec.	Diff.	Initial	After 15 Sec.	Diff.	Initial	After 15 Sec.	Diff.	Initial	After 15 Sec.	Diff.
Neoprene	B-156-315	(1) Mean	38	38	0	42	40	2	45	42	3	51	43	8	80	50	30	94	71	23
		S	.4899	.4899		.4899	.4000		.4899	.4899		1.3565	.4899		1.8330	.6325		1.1662	2.1354	
	B-156-290	Mean	44	43	1	48	47	1	51	48	3	66	49	17	92	61	31	94	74	20
		S	.0000	0		0	.4899		.7483	.4899		1.6248	.4000		1.0198	.9798		1.1662	1.3266	
Duna S	B-162-415	Mean	50	47	3	56	53	5	63	56	7	68	57	11	77	64	13	85	70	15
		S	.8000	.6325		.8000	.8000		.4000	.4000		.7483	.8000		1.0954	.6325		.7483	1.0954	
	B-162-489	Mean	54	51	3	60	55	5	63	58	5	66	57	9	71	61	10	76	65	11
		S	.8000	1.1662		.4899	.4899		.4000	.4000		.6324	.4899		.8000	.4899		.7483	.8000	
Perbunan-26	B-194-368	Mean	54	46	8	68	57	11	73	63	10	86	69	17	96	94	2	96	96	0
		S	.7483	.7483		.4000	0		.6324	.4000		1.0198	.7483		1.0198	.7483		1.0198	1.0198	
	B-194-234	Mean	48	44	4	56	50	6	61	53	8	66	55	11	82	64	18	93	78	15
		S	.4000	.4000		.7483	.7483		1.2000	.7483		1.4967	1.1662		.9798	.8944		.0000	1.0198	
Hevea	B-13-92	Mean	34	33	1	37	36	1	37	36	1	35	34	1	34	33	2	41	37	4
		S	.4000	0		.4000	0		.4899	0		.4899	.4899		.0000	.0000		1.1662	.4000	
	B-13-173	Mean	35	34	1	37	36	1	38	37	1	37	35	2	37	36	3	48	38	10
		S	.4899	.7483		.7483	.4899		.4000	.4000		.4899	0		.5000	.5000		.7483	.4000	
Butyl	B-34-104	Mean	45	43	2	50	47	3	55	48	7	68	48	20	83	52	31	87	55	32
		S	.4899	.4000		.4899	.4000		.6324	.4000		.7483	.4000		1.0954	.8000		1.7205	1.1662	
	B-34-105	Mean	50	48	2	58	53	5	65	54	11	74	54	20	86	60	26	89	63	26
		S	.4000	0		0	.4000		.6324	.6325		.7483	.7483		1.2000	.6325		.8000	1.0954	
Thiokol FA	B-53-15	Mean	61	56	5	68	62	6	73	66	7	77	68	9	88	76	12	92	78	14
		S	.8000	.9798		.4000	.8000		.7483	1.0198		1.1662	.4000		1.4967	1.0198		1.1662	1.4967	
	B-53-17	Mean	56	50	6	65	58	7	72	63	9	82	68	14	89	77	12	94	82	12
		S	1.0198	1.0198		.6324	.4899		.4899	.8000		1.4967	1.2000		.7483	1.2649		.4899	.7483	

(1) N = 5 (Readings in each run
S = Standard deviation

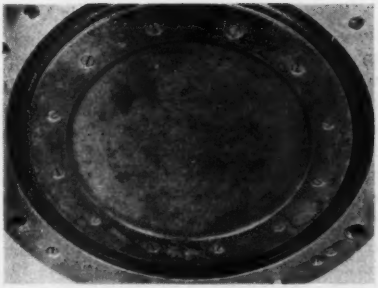


FIG. 11—Shows close-up of groove in gasket after 2 weeks at +20° F showing deep groove.

FIG. 12—Shows close-up of gasket in sealing apparatus after recovery to normal temperature.

kets tested. On a quick-acting door, torque values ranging from 90 to 160 foot-pounds were required to seal against leakage at 15 psi hydrostatic pressure, for the different gasket stocks. Different operators were able to exert torques from a comfortable minimum of 70 to a maximum of 280 foot-pounds. On tests using a dog-type door it was found that by applying an equal torque to the individual dogs, torques from 35 to 75 foot-pounds were required to seal against 15 psi hydrostatic pressure. Of course it should be pointed out that the torque values obtained on tests to seal against pressure and to indent into the gaskets, are subject to a number of variable factors, and must therefore be considered as approximate. These factors are inherent in the gasket materials and particular water-tight door construction presently in use, and were assessed properly in arriving at a limiting hardness value for gasket stock, see Table A.

A test of the force in foot-pounds which different operators can apply to the scuttle handwheel when mounted overhead and when mounted under foot determined indirectly the permissible hardness of the gasket rubber. A value of 60 Shore Hardness was set as the maximum hardness to be used at any time, even at temperatures of minus 35°F.

The extent to which chloroprene gaskets will deflect or groove is shown in Figures 11 and 12. Note the deep set which the gasket has taken after having been exposed to two weeks at temperatures of plus 20°F. This indicates that while the chloroprene gasket eventually returns to its original shape, it will not seal satisfactorily for a long time, once it has been subjected to a temperature of only plus 20°F. It is interesting to note, however, that chloroprene will frequently show less crystallization and hardening at somewhat lower temperatures than it does at temperatures of plus 20°F.

HOSE

An extremely important shipboard use of rubber is hose. Some thirty-four specifications cover the many different types and varieties of hose. The hose vary from large six, eight and ten-inch diameter oil and gasoline suction-and-discharge hose to smaller steam hose, air hose, sand blast hose, fire extinguishing hose, to oxy-acetylene welding hose, less than ½ inch in diameter. Of course there are also highly specialized hoses such as diving hose, submarine rescue chamber hose, and hot plastic paint hose. The latter is a heat resisting hose which has electrical connections for a bare resistance wire running the length

of the hose which maintains the contents at the desired high temperature. Since this hose has to carry hot plastic paint at 400°F under high pressure, it is necessary to protect personnel in case of an accidental burst to prevent the hot plastic paint from painful scalding or from bursting into flame as soon as it hits the air. A loose-fitting, heavy duck cover is fitted over the entire length of the hose. Then if a leak occurs, it will be immediately noticeable by the duck cover ballooning out. This will protect the personnel until the pressure can be shut off.

Another unusual hose is that used to provide fresh air and exhaust used air from submarine rescue chambers operating as deep as 1200 to 1400 feet below the surface of the water. These hoses must resist crushing pressures as high as 600 pounds per square inch, which is no mean feat for a light-weight flexible hose. Hoses used in certain hydraulic systems, must withstand bursting pressures up to 3000 pounds per square inch. This is generally accomplished by building the strength up in the carcass of the hose by the use of wire braid, in lieu of cotton, nylon or rayon fiber threat, not using just one layer, but often three or four layers.

The handling of all sorts of hose, particularly hose used in fueling operations from ship to ship, results in damage to the hose cover. A special technique has been developed for repairing any breaks in the outer rubber cover. This method is so simple that no special training is needed. Breaks, cuts, or worn spots in the rubber cover offer entrance to moisture, mildew and corrosion to the carcass or the wire reinforcing in the hose. A liquid polymer polysulfide compound was developed which is stocked in pint cans and which can be applied with a putty knife to the damaged area. Subsequently, it is taped to protect it while it cures itself, without loss in volume at room temperature. This so-called hose repair material can be applied to replace the normal covering by merely trowling the unvulcanized coating into the depression. The pint can, previously mentioned is a double can, the top portion of which holds the accelerator and the main or lower portion holds the bulk of the compound. Just prior to use, the accelerator is added to the liquid polymer and stirred. This unusual material will cure without application of any external heat in a matter of 3 to 4 hours provided the temperature is not less than 60°F. This liquid polymer polysulfide, is unique in that it will establish excellent adhesion to the rubber cover and to the exposed fabric regardless of whether the original cover was natural rubber, chloroprene or any of the other synthetic rubbers generally used for manufacturing hose covers. The process of hose repair has been described in detail in the official Navy Bulletin. Whenever the outer rubber cover of a hose has become torn or broken or gouged out, it is a foregone conclusion that sea water and dirt will get on the fabric reinforcement or will corrode the wire stiffening which will then repeatedly deteriorate the whole hose. The use of hose repair material is simple and will save the Government hundreds of thousands of dollars if promptly used. The resulting coating will generally resemble the original rubber coating and if properly applied will last the life of the hose.

Another special hose is illustrated in Figures 13 and 14. This hose was developed by Mr. Hamblin of the Bureau of Ships and is used wherever temporary ventilation has to be effected. Figure 13 shows the hose contracted to its minimum size and Figure 14 shows the hose fully expanded. In a recent test, this hose was subjected to 88 thousand flexes from minimum to maximum expansion in order to test its serviceability. The result of this severe test was satisfactory.

Recently, an extensive investigation was undertaken to determine the possible effect on aviation gasoline of the type of plasticizer used in compounding the synthetic rubber tube of gasoline suction-and-discharge hose. A very inter-

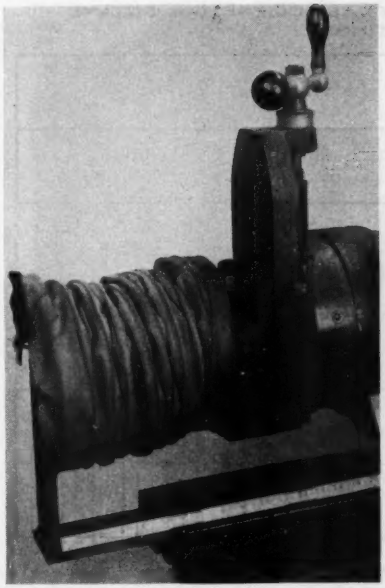


FIG. 13—Shows ventilating hose completely contracted.

FIG. 14—Shows the ventilating hose in expanded position.

esting discovery was made when some 46 different conventional plasticizers were evaluated. It was determined that the amount of non-volatile plasticizers extracted by the aviation gasoline was not the most important criterion of suitability of the plasticizer. For example, in some cases the amount of non-volatile constituent extracted was greater than of another type of plasticizer even though the deleterious effect on the gasoline was much less. All phosphate bearing plasticizers are likely to have deleterious effects on aviation type fuels by very materially decreasing the octane rating of the gasoline. Figure 15 shows a bargraph setting forth the relative decrease in octane number for various types of plasticizers. Table B lists the different types of plasticizers indicated numerically in the bargraph.

Since it will be noted that the deleterious effect of the phosphate-bearing plasticizers on the octane rating of the gasoline was approximately equivalent to the fortifying effect of the tetraethyl lead, it seems likely that the phosphate-bearing plasticizers reacted with the tetraethyl lead in such a manner as to either destroy or block it. It was observed during the extraction of these plasticizers that a slight precipitate formed. The quantity formed was insufficient for quantitative chemical analysis. However, spectroscopic examination of the precipitate disclosed that it consisted largely of lead phosphate. The phosphate-bearing plasticizers seems, therefore to react with the tetraethyl lead.

The extraction of the plasticizers from the stocks was accompanied by extraction of some of the other compounding ingredients, such as stearic acid, sulfur, antioxidant and accelerator. However, the influence of these materials on the octane rating was negligible since the significant changes were observed only when phosphate-bearing plasticizers were present. As a result of this investigation, the use of phosphate-bearing plasticizers in the manufacture of liners for gasoline hose and in fuel cells has been prohibited. Suitable tests to detect phosphate-bearing plasticizers has been included in specifications for gasoline hoses.

TABLE B

TRADE NAME	COMPOSITION
1. Dibutyl phthalate	Dibutyl phthalate
2. Dimethyl phthalate	Dimethyl phthalate
3. Diphenyl phthalate	Diphenyl phthalate
4. Diethylene glycol phthalate	Deithylene glycol phthalate
5. Methox	Methoxy glycol phthalate
6. Kronisol	Butoxy glycol phthalate
7. Dibutyl sebacate	Dibutyl sebacate
8. Dibenzyl sebacate	Dibenzyl sebacate
9. Tricresyl phosphate	Tricresyl phosphate
10. Carbonex S	Coal tar modified with fatty acid
11. KP-140	Tributoxy ethyl phosphate
12. Diisobutyl adipate	Diisobutyl adipate
13. Santicizer E-15	Ethyl phthalyl ethyl glycollate
14. Santicizer B-16	Butyl phthalyl butyl glycollate
15. KP-120	Methox glycol acetyl ricinoleate
16. Dibenzyl ether	Dibenzyl ether
17. Bardol	Coal Tar derivative
18. Bardol B	Coal Tar distillate
19. Barrett Oil #10	Coal Tar distillate
20. B. R. V.	Coal Tar distillate
21. S. R. O.	Refined coal tar
22. B. R. T. #7	Coal Tar distillate
23. Coal Tar #26	Coal Tar
24. Cumar P-25	Coumarone-indene resin
25. Cumar MH 2½	Coumarone-indene resin
26. Cumar AX	Coumarone-indene resin
27. Dipolymer Oil	Unknown
28. Advagum	Polyterpene
29. Pine Tar	Pine Tar
30. Hercolyn	Hydrogenated methyl abietate
31. Naftolen 510	Petroleum derivative
32. Piccocizer 30	Polymerized aromatic oil
33. Cardolite 25	Vulcanized vegetable oil
34. Cardolite 816	Vulcanized vegetable oil
35. Neophax A	Vulcanized vegetable oil
36. Tetralin	1, 2, 3, 4, tetrahydro naphthalene
37. Duraplex C-50-LV	Phthalic anhydride alkyd resin
38. Resin R-6-3	Soft non-thermoplastic resin
39. Triphenyl phosphate	Triphenyl phosphate
40. Triethyl phosphate	Triethyl phosphate
41. Di-n-butyl-acid-o-phosphate	Di-n-butyl-acid-o-phosphate
42. Pentabutyl-acid-tri-poly-phosphate	Pentabutyl-acid-tri-poly-phosphate
43. Monooctyl-acid-o-phosphate	Monooctyl-acid-o-phosphate
44. Ethyl-i-amyl-acid-o-phosphate	Ethyl-i-amyl-acid-o-phosphate
45. Mono-i-amyl-acid-o-phosphate	Mono-i-amyl-acid-o-phosphate
46. Ethyl-octyl-acid-o-phosphate	Ethyl-octyl-acid-o-phosphate

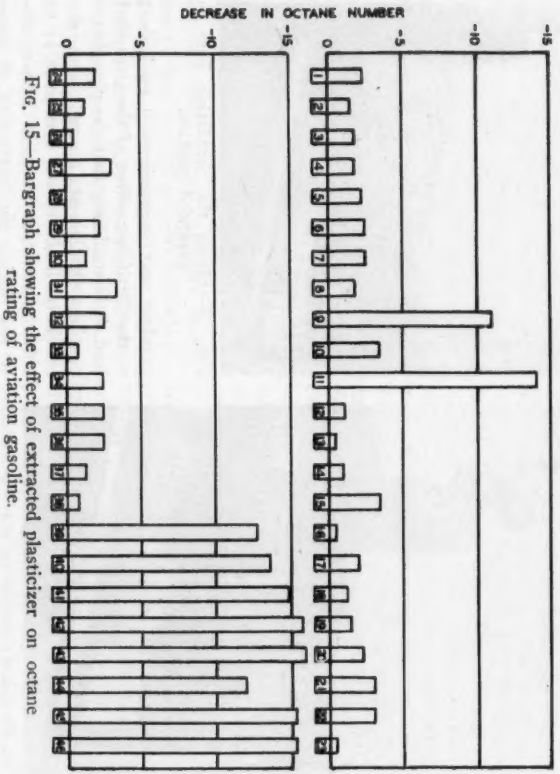


FIG. 15—Bargraph showing the effect of extracted plasticizer on octane rating of aviation gasoline.

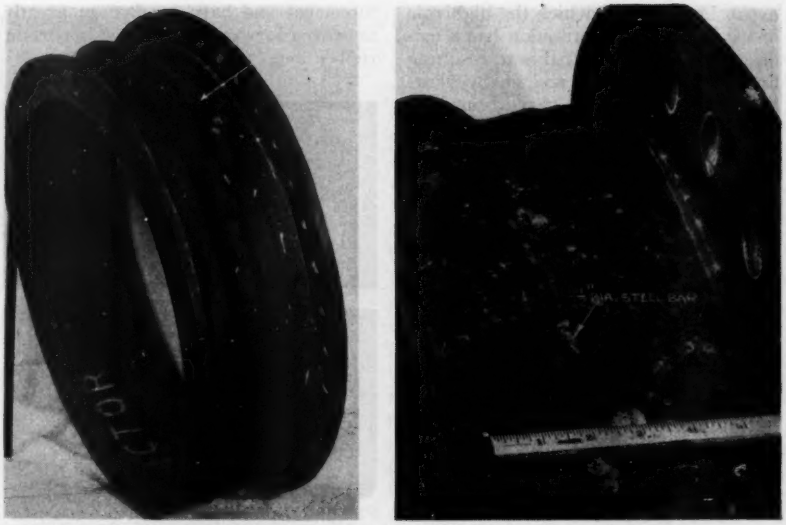


FIG. 16—Shows additional photographs of the 38" rubber injection scoop.

EXPANSION JOINTS

In addition to using rubber extensively in various types of hose, rubber is also used in permanently installed piping as expansion joints. The use of rubber for this purpose has been rather limited until recent evaluations which indicated that an expansion joint built of successive layers of chloroprene and asbestos had excellent fire retardant properties. A typical section of an expansion joint is shown in Figure 16. These chloroprene-asbestos expansion joints have shown excellent serviceability compared to natural rubber or metal expansion joints. An even larger expansion joint is shown in Figure 17. One of the most important advantages of using rubber and synthetic rubber expansion joints is the attenuation of noise transmitted to the hull of the ship which will decrease the chance of detection by enemy craft. The rubber joint has much greater serviceability than corresponding metal joints and has many times the service life of a metal joint. It is hoped that the development of this excellent fire retardant compound for the manufacture of expansion joints will greatly increase their use aboard ship. A cross section detail of the expansion joint shown in Figure 17 is shown in Figure 18. Both Figures 18 and 19 show the multi-layer type of construction.

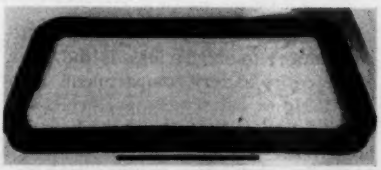


FIG. 17—Overall view of large rubber expansion joint.

Considerable advances have been made in developing synthetic rubbers which would show low internal heat build-up. The comparatively high internal heat build-up of most synthetic rubbers has precluded their use in heavy duty tires and similar applications such as these

expansion joints in which the high rate of expansion and contraction has a tendency to build-up internal heat, resulting first in ply separation and finally blow-out. Extensive testing, carried out both by the manufacturer and by the New York Naval Shipyard Material Laboratory, have brought out weaknesses in the construction and in the method of reinforcement and have resulted in greatly improved service life of these important rubber items.

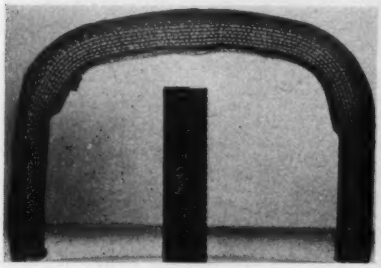


FIG. 18—Cross sectional detail of expansion joint.

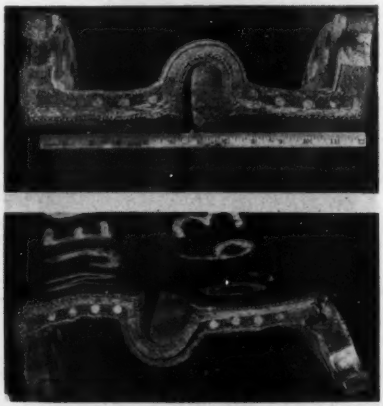


FIG. 19—Shows detailed construction of wire and fabric reinforcement of a 38" rubber scoop injection fitting.

MISCELLANEOUS APPLICATIONS

An extremely important use of rubber, limited to submarines, is the lining of the entire battery compartment. Rubber lining of battery compartments is a highly specialized technique which has been successfully accomplished by the Mare Island Rubber Shop and by two or three manufacturers. In most instances the lining of the compartment consists of two layers of sheet rubber applied in such a manner that scarfed seams never overlap. Vulcanizing of the lining generally is carried out at the low temperature of 125 to 140°F. The vulcanizing agent and accelerator in most cases is carbonbisulfide. In other applications the curing may depend on migration of accelerator from one sheet to the other. The rubber lining with sheet material is now being supplemented experimentally by a process using chloroprene applied by being brushed on in successive coats. Whereas the sheet lining is applied in a thickness no less than ¼ inch, the brushed-on type of coating is rarely more than 3/32 inch thick. In addition to protecting the inner hull of the submarine, from acid corrosion as a result of spillage of sulfuric acid from the batteries, it is believed that the lining contributes to protecting the storage batteries from the concussion caused by depth charges. Prior to World War II, the lining was either natural rubber or non-oil resistant synthetic rubber. It was determined however, by careful examination by our rubber laboratory technologists, that considerable damage was caused by hydraulic and diesel oil leakage, so that now all rubber lining jobs are made with oil resistant synthetic rubber.

Rubber appears in such highly specialized parts as submarine-hydraulic whip antenna-hydraulic actuator assembly. In this equipment a reinforced rubber diaphragm is required. Several stages of the manufacture of this

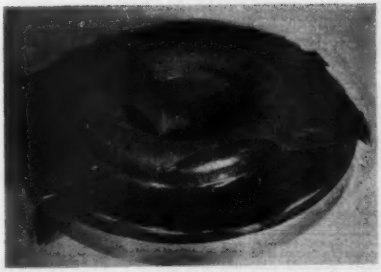


FIG. 20—Application of first layer of rubber and coated fabric of actuator diaphragm.

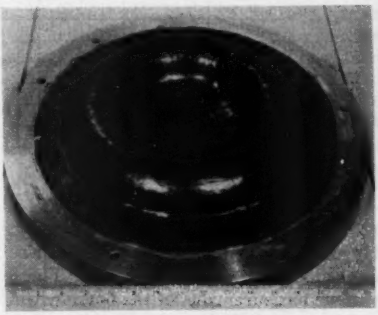


FIG. 21—Shows completed diaphragm ready for cure.

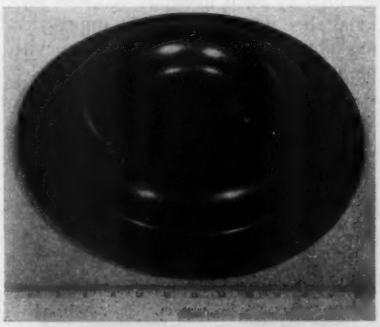


FIG. 22—Shows a finished diaphragm.

equipment are shown in Figures 20, 21, and 22, respectively. The details of the manufacture of this diaphragm are shown primarily for the purpose of demonstrating the excellence of the facilities and staff both at the Rubber Laboratory, Mare Island and at the Rubber Shop, Mare Island. This high degree of skill, training and ingenuity could be used more extensively wherever the design incorporates any rubber molded, built-up or extruded items.

Several years ago, the Rubber Laboratory in conjunction with the Bureau of Ships, designed a synthetic rubber spring to be used in conjunction with bogie wheels for aquatic tracked vehicles. A synthetic rubber spring greatly increases the shock absorbing characteristics of the track vehicles, and thus increases the overall life. When not using a rubber spring, the shock of the rough terrain was transmitted through the bogie wheel tire to the torsiolastic spring and bumper. In the Mare Island design, the shocks would be distributed between the bogie wheel tire, the rubber spring, the torsiolastic spring and the bumper, thus greatly decreasing the heat build-up within all four individual constituents. The use of rubber springs has been applied in street car wheels for several years. Figure 23 shows a set-up for radial deflection test with bogie wheel and synthetic spring assembly. By

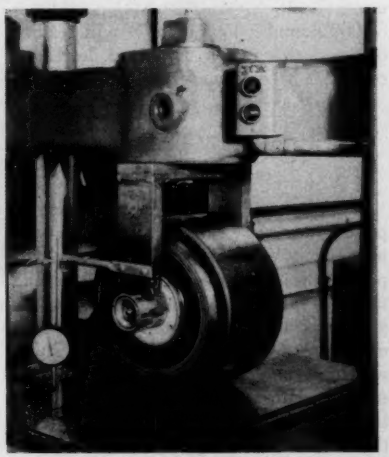


FIG. 23—Set up for radial deflection test with Bogie wheel and synthetic rubber spring assembly.

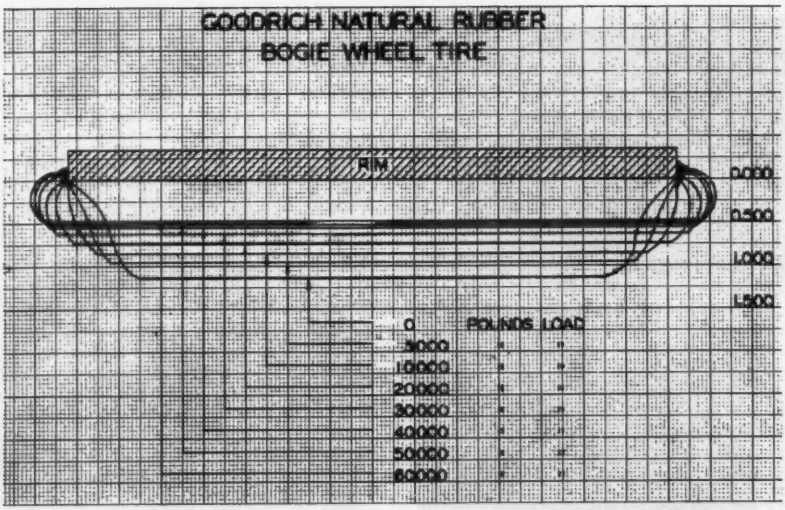


FIG. 24—Shows the load deflection characteristics of a Bogie wheel tire.

distributing the overall shock, it is feasible to use synthetic rubber instead of natural rubber in the construction of torsiolastic springs and bogie wheel springs, tires and bumpers. Figure 24 shows the deflection of the rubber tire under loads varying from 0 pounds to 60,000 pounds. From this it will readily be seen that when the total load exceeds 20,000 pounds, the bogie tire will be deflected sufficiently so that there is danger of having parts of the tire sheared off by the metal track. These contour measurements of the bogie wheel tire were made by pressing molding clay against the side of the tire when it was deflected by each loading. A cross sectional slice was cut from the impression thus obtained when it was frozen with the help of dry ice in acetone.

THE AIRFLEX CLUTCH

Rubber is often used in transmitting power from the prime mover to the propeller shaft and subsequently to the propeller. For example, it is used in the form of an expandable gland or tube known as an airflex clutch for reversing direction of rotation. The largest ships in which these airflex clutches have been used to date are some LST's transmitting 1500 horsepower per shaft. One of the first industrial applications of airflex clutches and brakes was in oil well drilling equipment where the constant

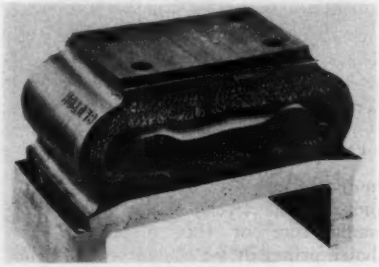
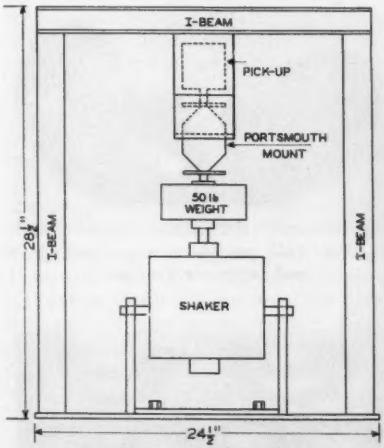


FIG. 25—Section through synthetic airflex clutch made with 98% synthetic rubber.

reversing constituted extreme strain on the equipment. Airflex clutches originally were constructed with 100% natural rubber. As a result of extensive investigations carried out jointly by industry and the Bureau of Ships, it was found that synthetic rubber clutches had longer life due to good oil resistance and generally a greater serviceability. Figure 25 shows a section through an airflex clutch which uses fully 98% of synthetic rubber.

MOUNTINGS

An extremely important shipboard utilization of rubber is in all types of vibration absorption mounts and noise attenuation equipment. Unfortunately, shock and vibration absorption mounts for shipboard use have to be designed on an entirely different basis than similar equipment for shore use because provision has to be made for the effect of gun blast and depth charge impact. Much extremely complicated testing has to be undertaken in order to evaluate various types of shock mounts. For example, Figure 26 shows a sketch of the equipment used in determining natural frequency. The shock absorbing and resilience characteristics of rubber change considerably with temperature. Figure 27 shows equipment for determining resilience. Figure 28 shows a chart giving the change in natural frequency at various temperatures. Figure 29 shows another stock in which the natural frequency is much less effected by temperature.



APPARATUS FOR DETERMINING NATURAL FREQUENCY OF PORTSMOUTH SPOOL-TYPE MOUNTS

FIG. 26—Shows apparatus for determining natural frequency of mounts.

FIG. 27—Shows recording drum of Yerzley apparatus for determining resilience at low temperatures.

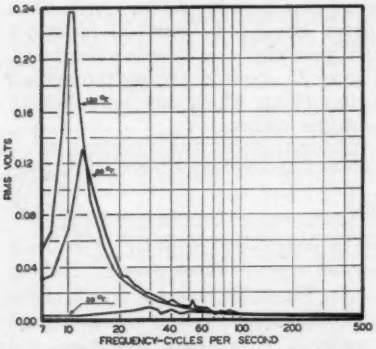


FIG. 28—Shows change in natural frequency at various temperatures of stock E-21-735.

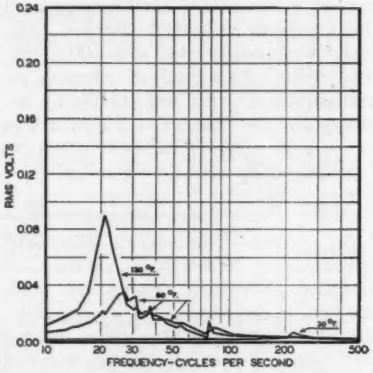


FIG. 29—Shows another stock (E-21-736) in which the natural frequency is much less effected.

MANUFACTURING PROBLEMS

In order to give the reader some conception of the difficulty of manufacture of some rubber items and to show the excellence of our rubber technologists at the Mare Island Rubber Laboratory, there are appended four illustrations given respectively in Figures 30, 31, 32, and 33. It will be noted from these illustrations that the transducer assembly was made by molding two separate portions, scarfing, cementing, and fitting them prior to insertion into the mold. This particular assembly was cured in a hydraulic press by vulcanizing for 60 minutes at 270° F. During curing the tube was inflated with 800 pounds per square inch of nitrogen pressure in order to insure uniform contact with the mold surface. Of course an inert gas had to be used. A relatively long cure, i.e., one hour has to be given. The 800 pounds internal pressure was introduced through one of the thickened portions of the transducer by means of a hypodermic needle.

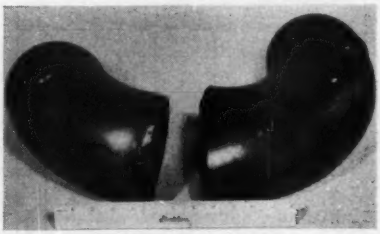


FIG. 30—Two sections of transducer scarf and ready for assembly.

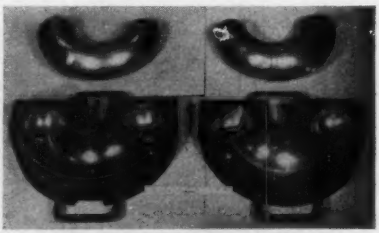


FIG. 31—Showing top and bottom of transducer assembly mold.

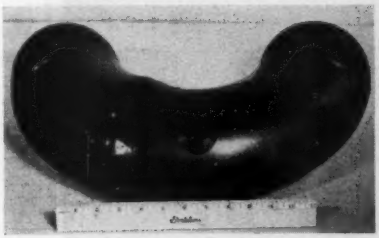


FIG. 32—Sections cemented and ready for mold.

FIG. 33—Completed transducer assembly.

CONCLUSION

The extensive use of rubber aboard ship is relatively new. Unless the Bureau of Ships is informed of the good performance as well as any weaknesses or possible misapplications of rubber, it will not be possible to continually improve rubber items. The enormously increased complexity and diversity of uses of rubber in Naval application has required the development of over one hundred additional testing techniques by the laboratory experts in laboratories under Bureau of Ships cognizance. However, the final proof of fitness will always be its behavior on shipboard under normal operating and combat conditions. Almost complete conversion from natural to synthetic rubber during World War II was effected without any apparent deterioration in the quality or in the performance of any of the rubber items procured under some 148 different specifications. In a good many cases the conversion from natural rubber to synthetic rubber has vastly improved the engineering and the performance characteristics of the component part. When it is considered that natural rubber has been vulcanized, compounded, blended, calendered, rolled, for over 100 years, it can be seen how much we must learn about synthetic rubbers, which are less than twenty years old and have been used even less than that aboard Naval vessels. As more technical information is obtained, on the large number of synthetic rubbers, it will be apparent that extensive improvements may be expected. In addition, new uses for rubber aboard Naval vessels are continually being discovered. One of the largest contributions will be noise elimination on board Naval vessels. This will no doubt be responsible for many new applications of rubber in order to avoid transmission of noise or in absorbing noise already made.

SUBMARINE

Official U. S. Navy Photograph

WELDING HEAT TREATABLE ALUMINUM ALLOYS

MR. B. B. BURBANK

THE AUTHOR

Mr. BENJAMIN B. BURBANK, the author, received the Degree of B.S. from Bowdoin College in 1926. He was Research Chemist with the Technicolor Corporation from 1926 to 1932. Then he was Research Engineer with the Pejepscot Paper Company until 1942 when he entered the Bath Iron Works Corporation as Chemist and Metallurgist.

1. *Processes*

The welding of aluminum alloys is not new but during the last few years great improvements in strength and corrosion resistance have been made in such welding by the introduction of two new methods of welding, namely, the "Heliarc" and "Aircomatic" processes. The other methods of welding aluminum are Flame Welding, Direct Metal Arc Welding and Carbon Arc Welding. These last three methods require the use of flux materials and for many purposes where corrosion is a serious problem, they are not satisfactory.

The "Heliarc" and "Aircomatic" methods do not require flux materials as they make use of an inert gas, either helium or argon, to shield the arc, hence they are generally termed "inert gas shielded arc welding." In the case of the "Heliarc" process, an arc is established and maintained between the work and a pure tungsten electrode, the entire arc being enveloped in a continuous supply of helium or argon gas. Into this shielded arc, filler rods are introduced and melted down to build up the weld bead.

The "Heliarc" process produces a very sound weld, free of inclusions and gas porosity. It gives the operator complete control over penetration and the welds are excellent in all respects. Its disadvantages are that it is a relatively slow process and it is difficult to use in confined and remote places, since the operator must use both hands to operate the electrode and filler rod. Many times on large weldments and especially aboardship, the operator must use one hand to hold himself in position and in such cases the "Heliarc" process is difficult to operate. The use of this process on outdoor fabricating

NOTE: The Author refused remuneration for this article.

in freezing weather is difficult since the process requires a circulating coolant, usually of water, for the torch head.

The "Aircomatic" process is basically similar to the "Heliarc" but in place of the tungsten electrode, an aluminum filler wire is automatically fed by mechanical means toward the work while the arc plays off its end supplying molten metal to build up the weld bead. The same principle of helium or argon gas shielding is used.

The chief advantage of the "Aircomatic" process is the speed of welding. This speed is as high as five times that of the "Heliarc" process. Besides a great saving in time, this higher speed of welding results in much less heat absorption by the welded parts and consequently far less distortion. The welds made by "Aircomatic" have excellent surface appearance and good penetration. The operator has one hand free to support himself for difficult positions and the torch will get into more difficult confined areas. Another advantage is that no coolant is used so that this process is better for wintertime outdoor work.

In early use of the "Aircomatic" process, considerable gas porosity was encountered. At the present time this has almost all been eliminated but constant attention on the part of the operator is necessary to keep the filler wire absolutely clean and dry.

Photographs (a) and (b) show typical units of each process used on productive work.

Photograph "A" Aircomatic Process

Photograph "B" Heliarc Process

2. *Fundamentals of Heat Treatment*

A very brief review of the fundamentals of heat treating alloys of aluminum will clarify and establish terms that will be used throughout this article. There are many aluminum alloys that respond to what is known as precipitation hardening, sometimes called age hardening. They are alloys of aluminum and some other element or elements of such a nature that these minor alloying agents will wander about within the solid aluminum at temperatures below the melting point. By proper temperature control, well below the melting point, these alloying elements may be completely dispersed throughout to produce an homogeneous alloy or regimented to localized areas producing a non-homogeneous condition. The physical properties of such an alloy depend upon the dispersion or grouping of these alloying substances. Therefore it is possible to control the physical properties of the alloys by temperature treatment.

Just what the mechanism of this heat treatment is may be more easily understood by reference to the sketches, Figs. 1, 2 and 3.

In Fig. 1, the softest fully annealed or "0" condition is depicted. The alloying agent has migrated to the grain boundaries and deposited between the faces of the crystals of aluminum itself. In the case of alloys like 24S, this area would be copper rich. For alloys like 53S and 61S this area would be magnesium and silicon rich. This condition prevails if temperatures of 600°F to 800°F are met and the alloy allowed

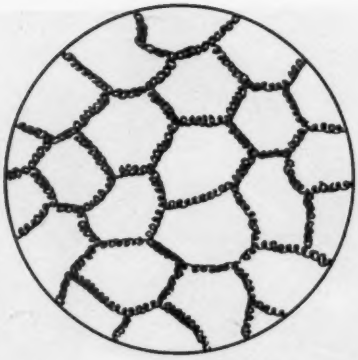


Fig. 1
Fully Annealed
Softest Condition
"O" Condition

Fig. 2
Heated To 980° F.
Cold Water Quenched
T4 Condition

to cool slowly. The migration will not reverse itself at normal temperatures. If the temperature of the alloy is raised over the critical which is about 900°F a reverse migration sets in.

Fig. 2 shows the condition at 980°F wherein all the alloying agent is uniformly dispersed throughout the aluminum crystalline structure. To hold this, a sudden chilling is required. By quenching in cold water the alloy cools so fast that the alloying agent is frozen in its tracks and all uniformly distributed. Infinite time at normal temperatures will result in migration of the alloying agent back to the grain boundaries. To some extent this is termed age hardening. The condition of the aluminum alloy after quenching from 980°F is known as Solution or T4. In this condition it is somewhat stronger than the "0" or fully annealed state but not as strong as it is possible to make it.

Fig. 4 shows graphically what happens to the physical strength of the

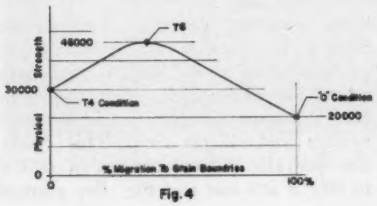


Fig. 4

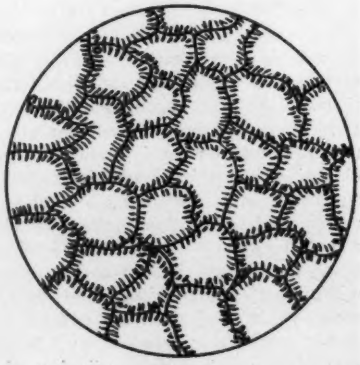


Fig. 3
Precipitation Hardened
320°F. - 16 Hrs.
T6 Condition

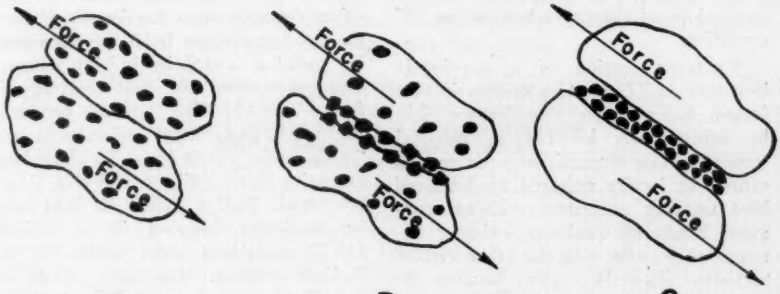


Fig. 5

alloy as migration of the alloying agent proceeds back toward the grain boundaries. The strength increases rapidly at first, reaches a maximum at the T6 condition and then falls off gradually to finally end up in the soft "0" condition. Heat and time promotes this migration. 320°F for 16 hours will promote sufficient migration to result in the maximum strength, T6 condition. Higher temperatures for shorter periods, or longer time at lower temperatures may be substituted to gain about the same result.

The increase in the physical strength caused by the migration of the alloying agent is explained quite simply as follows. See Fig. 5.

The physical strength of a metal is dependent upon the slip of component crystals one upon another as force is applied.

Let us consider two aluminum crystals of an alloy. In Fig. 5A all the alloying agent is dispersed as dark spots quite uniformly distributed within the crystals proper. Fig. 5B shows partial migration toward the grain boundaries and Fig. 5C complete migration to the grain boundaries. In the case of Fig. 5A some force will be required to cause inter-facial slip but in Fig. 5B a greater force will be required because of the interlocking action or dove-tailing of the migrant alloying agent. In Fig. 5C, however, complete migration results in the weak "0" condition where the alloying agent exists as granules more free to roll along the crystalline interface. So it happens that when the optimum amount of the alloying agent has migrated into the crystalline interface the strength of the aluminum alloy will be maximum. The most responsive alloying agents in this respect are copper and the twin combination of magnesium and silicon. Copper alone responds well but silicon alone gives no increase.

3. *Effect of Welding Heat on Heat-Treated Aluminum Alloys*

Any temperature increase over about 200°F for any appreciable time will decrease the physical strength of a heat treated aluminum alloy more or less in proportion to the temperature and time. For example, 400°F cannot be endured over 15 minutes without appreciably lowering the physical strength. This is evident from the graphical illustration in Fig. 4. Increased temperature and time promotes increased percentages of migration of the alloying agent to the

grain boundaries which is on the downward slope of the curve toward the "0" condition.

Whatever section of a previously heat treated T6 Aluminum alloy is subjected to a high temperature will be substantially lowered in physical strength. The strength of such section cannot be locally restored by localized heat treating procedure without marginal bands of weakness existing between such areas and the other distant sections. This is logical because no system of heating can be set up that does not somewhere have a temperature gradient zone between that and the remainder of the piece. The temperature gradient zone will present material in all stages of heat treatment from "0" thru T4 to T6.

The heat of the welding arc is high and it has a profound effect upon the physical properties induced in the aluminum alloy by the previous heat treatment. It greatly lowers the physical strength along a marginal zone each side of the weld. The extent of this effect depends upon the length of time the welding process holds the surrounding metal at a sufficiently high temperature to destroy the heat treating effects. The "Heliarc" process produces the most pronounced effect and the "Aircomatic" much less. To show how extensive this is, Fig. 6 and Fig. 7 are presented. Fig. 6 shows the heat zone or weakness induced in a ⅛-inch 61ST6 aluminum plate welded by the Heliarc process. The same thing for a 1½" plate is shown in Fig. 7. Thus it is very evident that the strength is discounted some 40% to 50% by the welding and extends over an appreciable area both sides of the weld.

Fig. 8 and Fig. 9 show comparable conditions for "Aircomatic" welding. Owing to the speed of this process and no preheating for thick sections, the strength is discounted far less but nevertheless does exist to a serious degree.

If heat treatable alloys are welded,

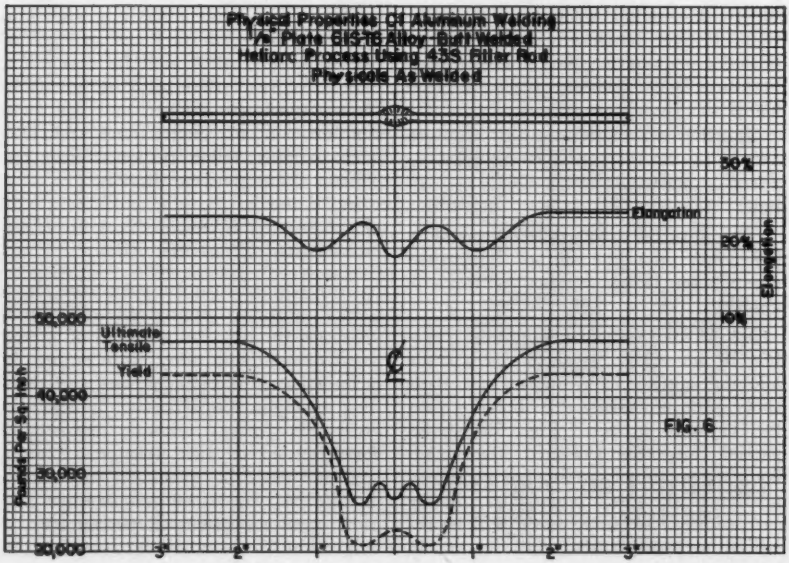
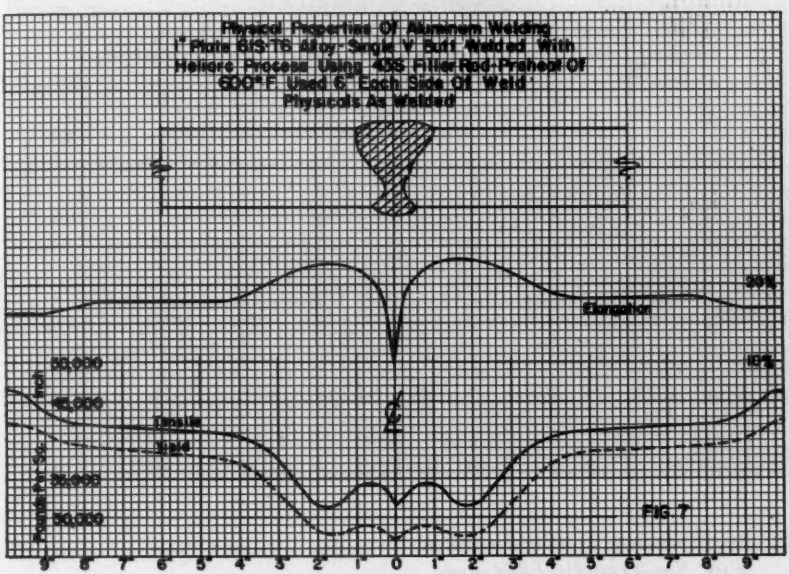
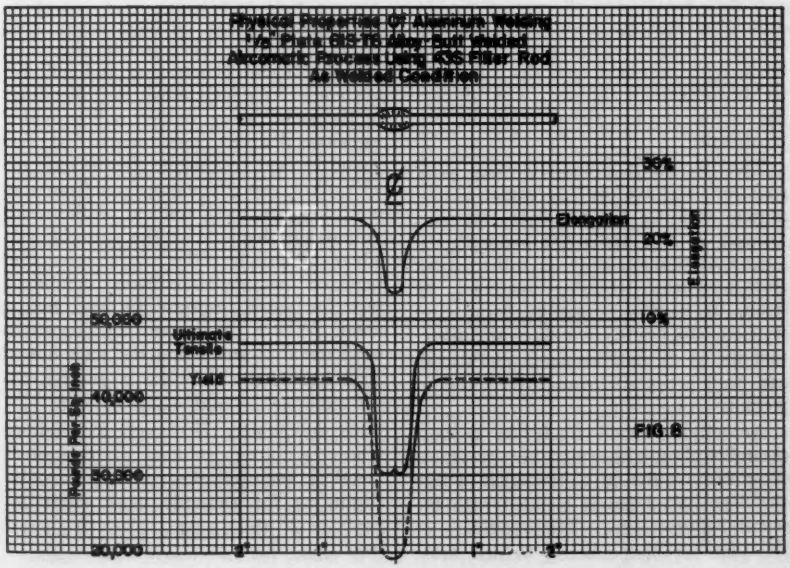
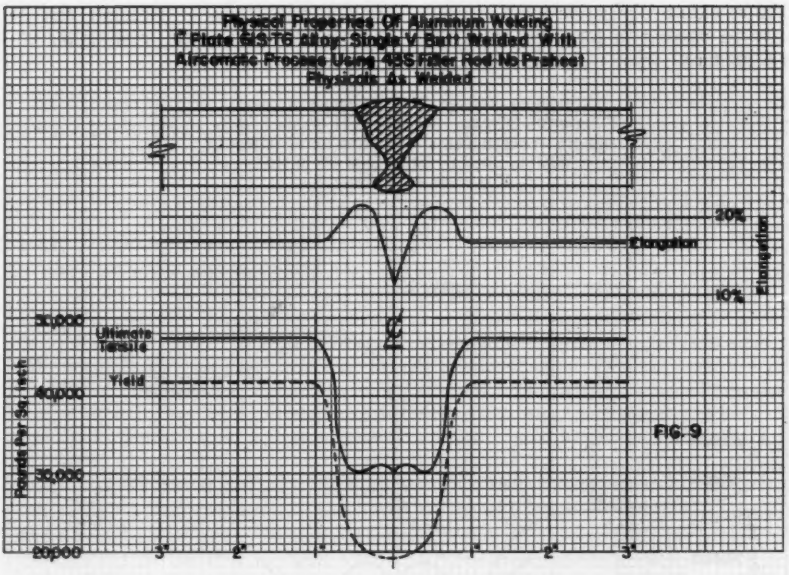


FIG. 6

the resultant fabrication must of necessity be weaker in localized areas than the material from which it is made up unless restoration of strength can be accomplished by reheat-treating the entire fabrication.







4. *Heat Treatment of Weldments Made With Non-Treatable Filler Rod*

It is not possible to realize maximum strength from heat treatment of welds made with non-heat treatable filler rod on heat-treatable alloys. The thicker the section the less the response to heat treatment.

The two most commonly used filler rods for "Heliarc" or "Aircomatic" aluminum welding are not heat treatable. Oxweld 23 and Alcoa 43S are both 5% silicon aluminum alloy, a rather weak and non-heat treatable material by itself. It is used primarily because of its excellent fluidity which is an important factor in maintaining a liquid pool and well penetrated and fuzed bead of welding.

Actually, a weld made on a heat treatable alloy with a non-heat treatable filler rod results in a condition where the deposited metal is blended with the metal being welded. The shoulders of the plate or shape being welded must be more or less melted down and blended with the filler rod or the weld has insufficient penetration and will be unsound. Any melt down and blending of the metal being welded will provide, to some degree, constituents that respond to heat treatment. In the case of 61S alloy, enough magnesium from the melt down of the shoulders of the weld preparation blend with the straight 5% silicon aluminum filler rod to give the required magnesium-silicon combination for some response to heat treatment. Where the amount of deposited weld metal is small and the melt down considerable the response is greater, as for example, in butt welds of plate ⅜" thick and under. However, in welding where a large volume of deposited metal is required the response is only slight, as for example, butt welds in 1½" or 2" thick plate. Fig. 10 shows this effect for 61S alloy butt welds.

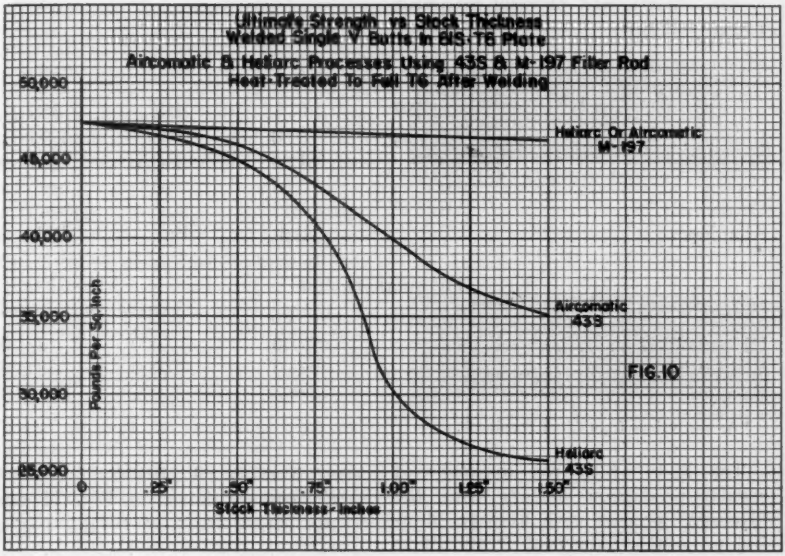


FIG. 10

5. *Heat Treatable Filler Rod Alloys*

It has been established that a welding filler rod for alloys 53 and 61, to respond to heat treatment, must contain magnesium and silicon. There is a commercially available alloy that meets this requirement, Alcoa 356, containing 7.0% silicon and 0.3% magnesium. This alloy, used with the "Heliarc" process, gives heat treatable welds of strength approximately equal to the base metal being welded. The corrosion resistance, however, is slightly inferior to the 43S non-heat treatable rod and considerably less than the base metal being welded.

Since the 356 alloy has an entirely different analysis than 53S or 61S (the base metal to be welded) it is not the most satisfactory under conditions of severe corrosion. Many attempts have been made to weld these base alloys with filler rods made of the same analysis. Cracking of welds during welding, or during cooling of welds, seems to be almost universally true under such conditions and the use of such filler rods has been abandoned.

By modification of the two alloys involved, i.e., the base metal 61S and the filler rod 43S, a compromise filler alloy is possible and has been used quite extensively for large heat treatable weldments. The new filler rod is neither 61S or 43S by analysis and has been designated as alloy M-197. It was developed in the laboratory by the Bath Iron Works Corporation, Bath, Maine, and has been manufactured in various size wires on a semi-production basis by the Aluminum Company of America under designation of alloy M-197. This alloy filler rod works equally well on either "Heliarc" or "Aircomatic" processes and something like 200 pounds of it were consumed in welding by "Heliarc" on a single large, thick-section weldment in connection with a U.S. Naval project.

The analysis and physical properties are as follows:

CHEMICAL ANALYSIS

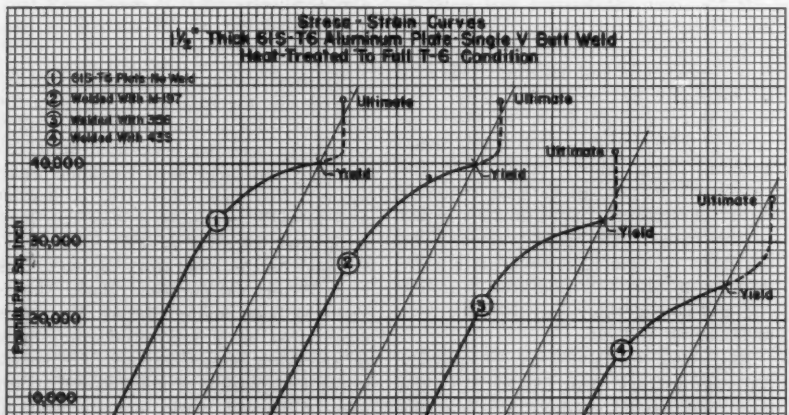
	M-197	61S	43S	356
Silicon	2.38%	0.60	5.00	7.00
Magnesium	0.60	1.00	—	0.30
Copper	0.15	0.25	—	—
Chromium	0.15	0.25	—	—
Aluminum	Bal.	Bal.	Bal.	Bal.

PHYSICAL VALUES

	M-197-T6	61ST6	43S*	356*
Ultimate PSI	45,000	45,000	19,000	33,000
Yield 0.2% Offset	38,050	40,000	9,000	24,000
Elongation	6.2%	12.0%	6.0%	4.0%

* As cast values from Alcoa Handbook.

The M-197 filler rod in hands of regular production welders using the "Heliarc" process give average physical properties after heat treatment to full T6 condition as shown above. Under more ideal conditions higher values have been obtained and are entirely possible on production. Stress-strain curves, shown in Fig. 11 represent values obtained in the testing laboratory on 1½" 61S aluminum plate welded and subsequently heat treated to T6 condition.



6. *Corrosion Resistance of Welded Sections*

Corrosion resistance of heat treatable aluminum alloys such as 61S is at its maximum when the fully heat treated "T6" condition prevails and at its minimum in the fully annealed or "0" condition.

Welding heat reduces the T6 condition in proportion to the temperature and duration of time as has been already demonstrated. Therefore, the heat affected zone around a weld lowers the corrosion resistance. If the heat zone is wide, as produced by "Heliarc," the corrosion susceptible zone will be wide. If narrow as produced by the "Aircomatic" process, the corrosion susceptible zone will be narrow and close to the weld margin. This is, however, only the first half of the problem of corrosion resistance of welded joints in heat treated alloys such as 61S-T6. The deposited weld metal is the other half of the problem. If the deposited metal is the usual 43S it does not respond to heat treatment and even though the final weldment be heat treated to eliminate the corrosion susceptible heat zones about the weld, there will be even more pronounced corrosion of the 43S weld metal long before any attack on the pieces joined.

Using 43S filler metal and no subsequent heat treatment the weldment then becomes subject to localized corrosion of the heat affected zone and the deposited weld metal. Using 43S filler metal and subsequent heat treatment to full T6 condition the weldment then becomes subject to localized corrosion of the deposited metal.

Using alloy 356 or M-197 as filler metal and subsequently heat treating to T6 condition a weldment having uniform corrosion resistance is obtained.

Accelerated laboratory corrosion tests bear out the foregoing statements which apply to both stressed and nonstressed welds. This is shown in photographs c, d, and e.

Photograph—c—as welded.
Photograph—d—T6—cond.
Photograph—e—T6—cond.
43S—Aircomatic, Bar A
43S—Aircomatic, Bar B
M-197—Aircomatic, Bar C

In photo c, Bar "A" shows corrosion attack in the heat zone, the dark band surrounding the deposited 43-S weld metal. The heat zone corrosion is of the intergranular type but in time will result in pit type corrosion. The corrosion of the deposited weld metal is more extensive and much deeper. The porosity of the aircomatic weld has here been greatly enlarged by corrosive action.

In photo d, Bar "B" shows no corrosion of a serious nature except on the deposited weld metal where the action has been almost identical to that of Bar "A" above described. No heat zone exists because Bar "B" was heat treated to full T6 condition after welding. The 43S filler metal did not respond to heat treatment and only a change or refinement of grain of this deposited metal occurred which was not sufficient to materially arrest corrosion.

In photo e, Bar "C" shows no corrosion, only discoloration of the weld metal. This bar was prepared with the B-197 welding wire and heat treated to full T6 condition after welding.

Stress corrosion tests follow closely the plain corrosion illustrated in the photo, only intergranular corrosion is more pronounced and shows up sooner in every case except the M-197 weld that has been heat treated. In this case little or no corrosion was observed.

To reduce corrosion of aluminum welds to a minimum a heat treatable welding wire should be used and the weldment heat treated after welding.

MEASUREMENT ACCURACY REQUIREMENTS FOR BOILER TESTING

J. W. MURDOCK

THE AUTHOR

MR. MURDOCK was employed by the Boiler Division of the U.S. Naval Boiler and Turbine Laboratory in 1939. His first five years there were devoted to analyses of boiler test results. He was then transferred to work on instruments, becoming Superintendent of the Instrument Division when it was organized in 1947.

As Superintendent of that group he has participated in research and development of instrumentation in co-operation with the National Bureau of Standards, The American Society of Mechanical Engineers and the American Gas Association.

He has written papers concerning the Enthalpy of Super-heated Steam, the Testing of Boiler Casings, and the Measurement of Temperatures in High Velocity Steam, the first and second of which have been published in this Journal, the last in the A.S.M.E. Transactions.

INTRODUCTION

The Naval Boiler and Turbine Laboratory, a field activity of the Bureau of Ships, has been engaged in boiler testing for forty years. During that period many changes in boiler design, operating temperatures and pressures have taken place. Constant improvement in naval boiler performance, partly as a result of development by tests at this activity, has resulted in progressively higher efficiencies and absorption rates. Concurrently with boiler efficiency increases, the problem of measuring performance has been made more difficult by the higher pressures and temperatures as well as the reduction in heat losses.

Boiler test calculations at NBTL have been described by Mr. F. J. Wiegand*, but the instrumentation required for obtaining the basic data has not been previously published.

Recognizing need for improvement in instrumentation, the Bureau of Ships, in May 1947, instituted a project for devising superior instrumentation for marine machinery to permit more accurate performance analysis. One goal was modification to allow determination of performance to less than one-tenth of one percent error. The initial step, that of securing this accuracy in boiler testing, is discussed in this paper.

* "The NBTL Boiler Test Code" by Fred J. Wiegand—JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, Volume 53, No. 4, November 1941.

MEASUREMENT ACCURACY FOR BOILER TESTING

SCOPE

The present Naval Boiler and Turbine Laboratory Long Work form for boiler test calculations contains 147 items. Of these, 56 are for measurements, and the remainder for calculation. The comparatively large number is necessary because the form provides for the performance analysis of many boiler components as well as the overall heat balance.

By limiting the scope of this paper to factors involved only in the overall heat balance, the number of measurement items can be reduced to 9 and the number of absorptions and loss calculations may be combined into four as follows:

1. Heat absorbed by boiler
2. Heat lost in dry exit gases
3. Heat lost due to moisture formed by burning hydrogen
4. Heat lost due to moisture in air

The measurements which affect overall heat balance are as follows:

1) Flow of fuel oil
2) Flow of feed water
3) Temperature of feed water
4) Temperature of steam
5) Pressure of steam
6) Carbon Dioxide content of stack gases
7) Temperature of entering air
8) Temperature of stack gases
9) Psychrometric conditions

All calculations in this paper are based on the assumption that all of the water feed to the boiler is converted to superheated steam with none withdrawn as saturated steam from the steam drum. In the application of the charts shown to boilers of the bled-steam type additional calculations will be necessary but, unless the amount of saturated steam is large in comparison with the total, little error will result in their direct use. Assumptions have been kept at a minimum to facilitate this. If corrections are desired then they may be made by the general method outlined below.

The equations, sources, and sample calculations involved in the preparation of each chart are indicated thereon. This will assist in the application of these figures to different types of heat transfer devices or to commercial boilers burning other fuels.

GENERAL METHOD

The aim of performance analysis to one-tenth of one percent error was used as a basis for calculating the accuracy necessary for each measurement, considering it individually with the heat balance item affected by it. These heat balance items were combined into a single equation. From this, two equations were made up, the first being considered as true, with the measurement under consideration being denoted with the subscript x, the second as the measured value designed with the subscript y. The second equation was then subtracted from the first. The result of this subtraction yielded an equation equivalent to the amount of error due to measurement. This method automatically eliminated items in the equation which did not affect the measurement under consideration. A value equivalent to one-tenth of one percent of the overall heat balance was then substituted for (x-y) and the final equation solved. Each of the remaining variables in the final equation were tried in turn to provide for all reasonable boiler conditions. From these calculations, the charts were drawn.

This method will *not necessarily result in an overall heat balance accuracy of one-tenth of one percent* even if all the measurements are made to the exactness required by these charts. The in-

tent of this study is to provide a basis for determining all measurements to the same relative degree of accuracy. It is intended that these charts will indicate which is the most inaccurate measurement so that a realistic attack on the problem of instrumentation may be made.

OIL AND WATER FLOW MEASUREMENTS — FIGS. 1 AND 2

The study for these charts was based on the weigh tank systems currently employed at the Naval Boiler and Turbine Laboratory. As can be readily seen the accuracy of these measurements is a function of time interval for any given boiler steaming condition. Tank capacities of 2,000 lbs. for oil and 20,000 lbs. for water allow, with proper operating techniques, attainment of almost any desired accuracy.

FEED WATER AND STEAM TEMPERATURES, FIG. 3. AND STEAM PRESSURE, FIG. 4

The solution of error equations indicates that the accuracy of the water and steam measurements are a function of the boiler steam cycle. A wide range of these variables were selected to provide for possible future as well as present steam cycles for commercial and naval use. Since this study was primarily made for naval application, a feed water temperature of 240°F. and overall efficiency of 85% was assumed. Caution must accompany use of these charts for boilers operating at other feed temperatures or efficiencies.

The feed temperature as shown is practically independent of the cycle steam pressure and only slightly affected by temperature. A measuring device capable of meeting one boiler application should be suitable for all.

The steam temperature accuracy as shown varies considerably with cycle temperature and pressure. Although more latitude is allowed at the higher temperature, it is obvious that the difficulty of measurement will increase with the elevation of measured temperature. A steam temperature measuring instrument capable of universal application to all possible cycles would be difficult if not impossible to contrive. In the selection of a steam temperature measuring device, the operating pressure and temperature of the boiler must be a primary consideration.

The accuracy requirements for the measurement of steam pressure seem surprisingly low until it is considered that the change of enthalpy of steam for a change in pressure is small. The reader should bear in mind that this chart *shows only the heat balance* effect of pressure. For the determination of boiler component performance, accuracy of a much higher order will be required.

HEAT BALANCE ITEM AFFECTED

Heat absorbed by boiler
ASME long form item 112

$$h_1 = WH_s$$

h_1 = Heat absorbed by boiler - BTU/lb. Fuel
W = Actual evaporation per lb. fuel - lbs./lb.
H_s = Total heat absorbed per lb. of steam - BTU/lb.

METHOD OF SOLUTION

$$W = S/F = \frac{EC}{H_s}$$

Where

C = Calorific value of fuel - BTU/lb.
E = Boiler efficiency - Ratio
S = Water reading for same interval as oil reading - lbs.
F = Oil reading - lbs.

Let

x = true
y = measured

Then

$$h_x - h_y = \frac{C}{1000} = \left[\frac{1}{F_x} - \frac{1}{F_y}\right] H_s S$$

$$\frac{C}{1000} = \frac{(F_y - F_x)\ EC}{F_y}$$

$$F_y - F_x = \frac{F_y}{1000\ E}$$

ACCURACY OF OIL FLOW MEASUREMENT FOR 1/10 OF 1% HEAT BALANCE

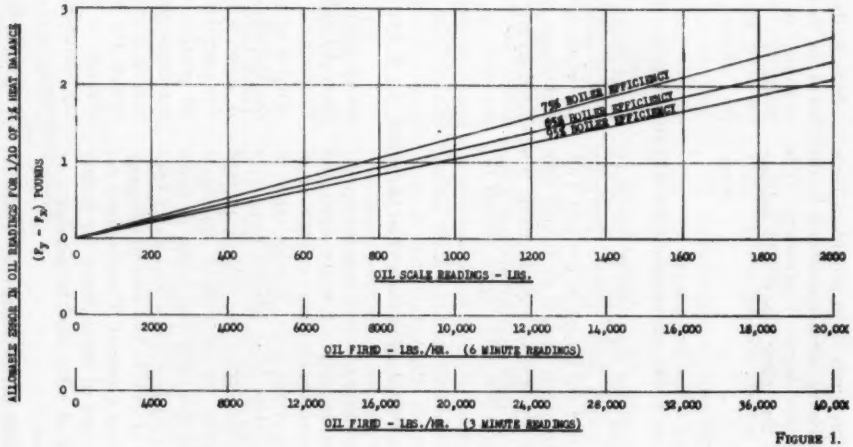


FIGURE 1.

MEASUREMENT ACCURACY FOR BOILER TESTING

HEAT BALANCE ITEM AFFECTED

Heat absorbed by boiler
WBTL Long form item 112

$$h_1 = WH_s$$

h_1 = Heat absorbed by boiler - BTU/Lb. Fuel
W = Actual evaporation per lb. fuel - Lbs./Lb.
H_s = Total heat absorbed per lb. of steam - BTU/Lb.

METHOD OF SOLUTION

$$W = S/F = \frac{EC}{H_s}$$

Where

C = Calorific value of fuel - BTU/Lb.
E = Boiler efficiency - Ratio
S = Water reading - Lbs.
F = Oil reading for same interval as water reading - Lbs.

Let x = true
y = measured

Then

$$h_x - h_y = \frac{C}{1000} = (S_x - S_y)\, H_s/F$$

$$F = \frac{S_x H_s}{EC}$$

$$\frac{C}{1000} = \frac{(S_x - S_y)\, EC}{S_x}$$

$$S_x - S_y = \frac{S_x}{1000\, E}$$

ACCURACY OF WATER FLOW MEASUREMENT FOR 1/10 OF 1% HEAT BALANCE

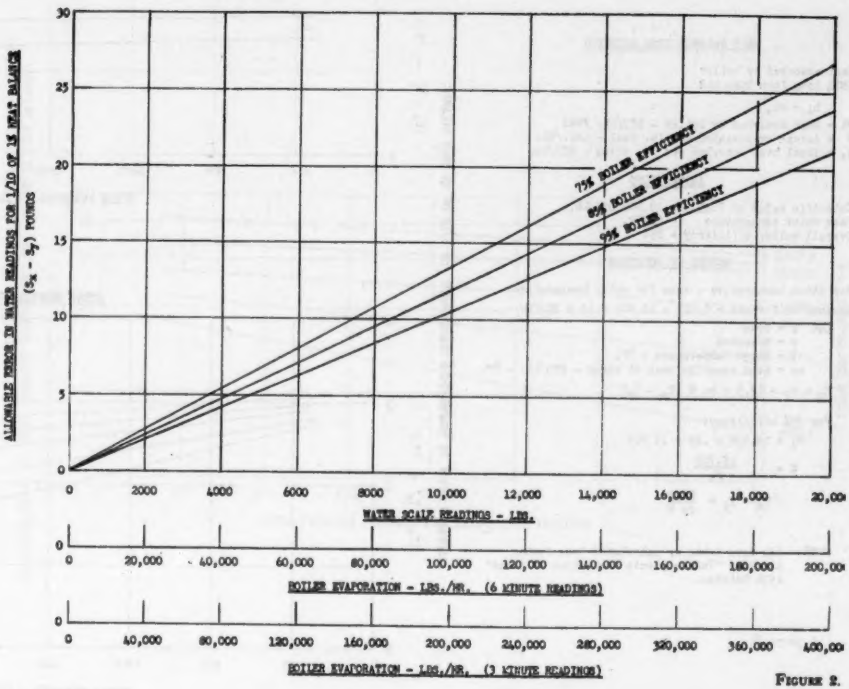


FIGURE 2.

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ACCURACY OF STEAM AND WATER TEMPERATURE MEASUREMENT FOR 1/10 OF 1% HEAT BALANCE ERROR

HEAT BALANCE ITEM AFFECTED

Heat absorbed by boiler
WBTL long form item 112

$h_1 = WH_s$

h_1 = Heat absorbed by boiler - BTU/Lb. Fuel
W = Actual evaporation per lb. fuel - Lbs./Lb.
H_s = Total heat absorbed per lb. steam - BTU/Lb.

ASSUMPTIONS

Calorific value of fuel = 18,500 BTU/Lb.
Feed water temperature = 240°F.
Overall boiler efficiency = 85%

METHOD OF SOLUTION

For steam temperature - same for water temperature
Maximum difference = 0.001 x 18,500 = 18.5 BTU/Lb.

Let x = True
y = Measured
T = Steam temperature - °F.
cp = Mean specific heat of steam - BTU/Lb. - °F.

$h_x - h_y = 18.5 = cp\ W\ (T_x - T_y)$

For 85% efficiency:

$h_1 = 18,500 \times .85 = 15,725$

$W = \frac{15,725}{H_s}$

$T_x - T_y = \frac{18.5}{cp\ W}$

NOTE: All data taken or calculated from Keenan and Keye "Thermodynamic Properties of Steam" 1936 Edition.

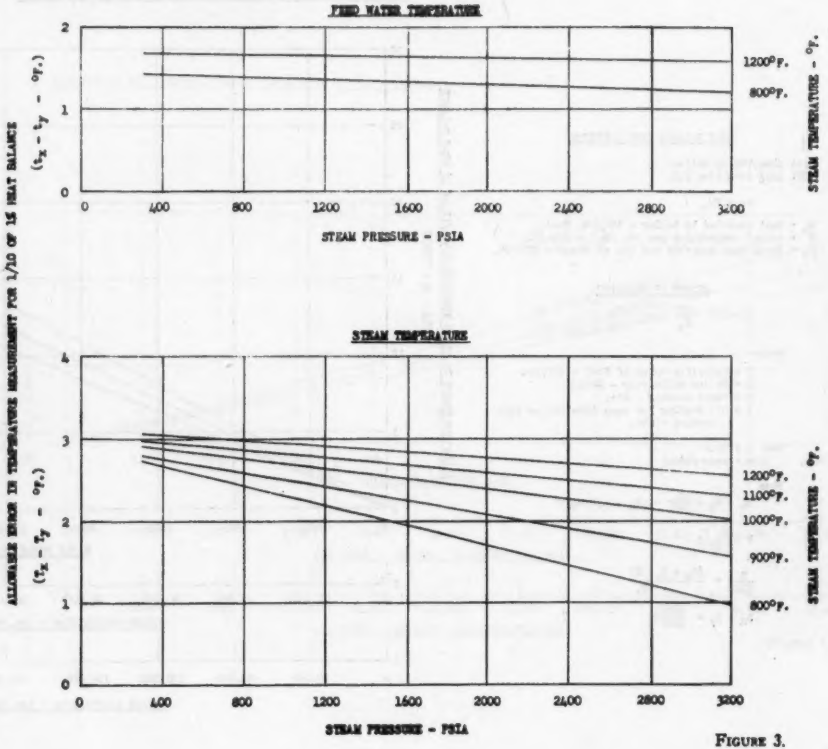

FIGURE 3.

HEAT BALANCE ITEM AFFECTED

Heat absorbed by boiler
ASME long form item 112

$$h_1 = Wh_s$$

h_1 = Heat absorbed by boiler - BTU/Lb. Fuel
W = Actual evaporation per lb. fuel - Lbs./Lb.
h_s = Total heat absorbed per lb. steam - BTU/Lb.

ASSUMPTIONS

Calorific value of fuel = 18,500 BTU/Lb.
Feed water temperature = 240°F.
Overall boiler efficiency = 85%

METHOD OF SOLUTION

For steam temperature - same for water temperature

Maximum difference = 0.001 x 18,500 = 18.5 BTU/Lb.

Let x = True
y = Measured
P = Steam pressure - PSIA.
B = Interpolation factor from steam tables - BTU/Lb. - PSI

$$h_x - h_y = 18.5 = B(P_x - P_y)$$

For 85% efficiency:

$$h_1 = 18,500 \times .85 = 15,725$$

$$W = \frac{15,725}{h_s}$$

$$P_x - P_y = \frac{18.5}{B}$$

NOTE: All data taken or calculated from Keenan and Keyes "Thermodynamic Properties of Steam" - 1936 Edition.

ACCURACY OF STEAM PRESSURE MEASUREMENT FOR 1/10 OF 1% HEAT BALANCE

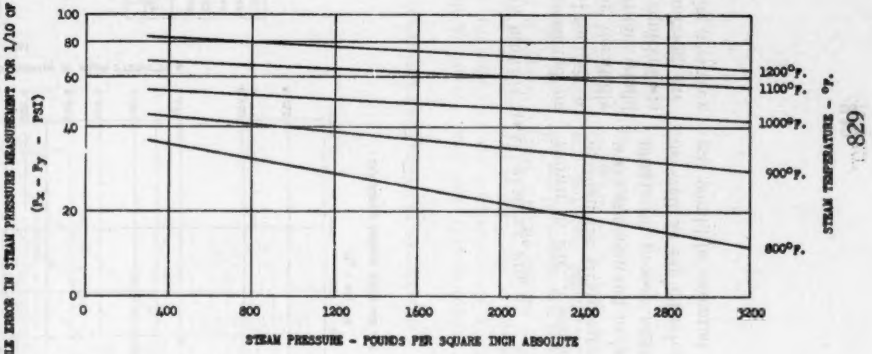

FIGURE 4.

HEAT BALANCE ITEM AFFECTED

Heat lost in dry exit gases
NAVY long form items 104 + 107 + 109

$$h_g = C_p\, G\, (T_g - t_a)$$

h_g = Dry gas loss - BTU/Lb. fuel
C_p = Specific heat of dry gas - BTU/Lb. - °F.
G = Lbs. of dry gas per lb. fuel - Lbs./Lb.
T_g = Temperature of gas leaving stack - °F.
t_a = Temperature of air at inlet - °F.

ASSUMPTIONS

Fuel analysis C = 86%, H = 11%, S = 1%
Calorific value of fuel = 18,500 BTU/Lbs.
Specific heat, dry gas = 0.25 BTU/Lb. - °F.
Carbon monoxide not formed

METHOD OF SOLUTION

Max. differential 0.001 x 18,900 = 18.5 BTU/Lbs.

Let h_x = true loss — G_x = true weight
h_y = measured loss — G_y = calculated weight

Then

$$18.5 = h_x - h_y = C_p(T_g - t_a)(G_x - G_y)$$

$$G_x - G_y = \frac{18.5}{0.25\,(T_g - t_a)}$$

$$G = \left[\frac{\%\,CO_2 + O_2 + 720}{3\,CO_2}\right]\left[\frac{C + \frac{3}{8}S}{100}\right]$$

For assumed oil

$$O_2 = 20.99 - 1.266\,CO_2$$

$$G = \left[\frac{3.704\,CO_2 + 720.92}{26CO_2}\right](0.8665)$$

VALUES CALCULATED FOR CURVES

% CO_2	G	$(CO_{2y} - CO_{2x})$ for $(T_g - t_a)$			
		200°F.	400°F.	600°F.	800°F.
15	14.985	0.402	0.198	0.132	0.098
12	18.532	0.256	0.126	0.084	0.063
10	22.078	0.177	0.088	0.058	0.044
8	27.536	0.113	0.056	0.037	0.028
6	43.366	0.044	0.022	0.015	0.011

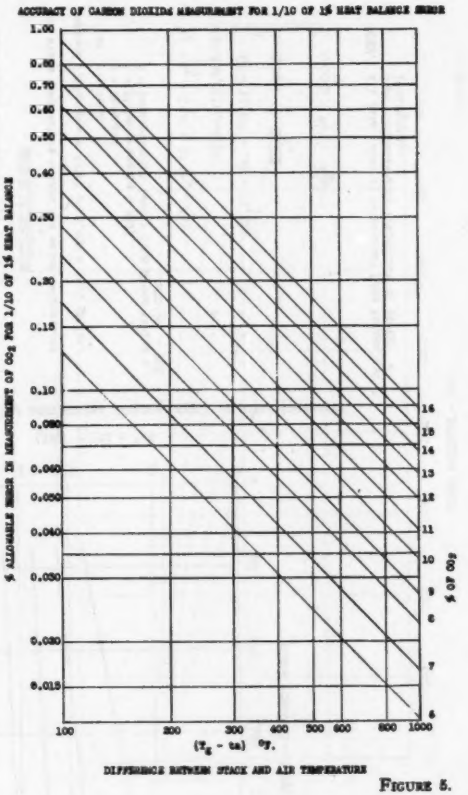

FIGURE 5.

CARBON DIOXIDE MEASUREMENT, FIG. 5

This chart has been constructed on the basis of an average naval fuel oil. A fuel oil or other fuel having decidedly different chemical composition would modify the accuracy requirements shown. A system for determining carbon dioxide percentage to the accuracy shown in Fig. 5 would have to take in account the stratification of flue gas always encountered in boiler stacks. Emphasis on proper methods of sampling as well as the chemical analysis of the gas would be essential.

ACCURACY OF GAS AND AIR TEMPERATURE MEASUREMENT FOR 1/10 OF 1% HEAT BALANCE ERROR

HEAT BALANCE ITEMS AFFECTED

Heat lost in dry exit gases
ASME long form items 104 + 107 + 109

Heat lost due to moisture formed by burning hydrogen
ASME long form items 101 + 110

$$h_g + h_3 = C_p\, 0\, (T_g - T_a) + M\,(1089.0 + .46\, T_g - t_a)$$

h_g = Heat lost in dry exit gases - BTU/Lb.
h_3 = Heat lost due to moisture from burning H_2 - BTU/Lb.
C_p = Specific heat of dry gas - BTU/Lb. - °F.
0 = Lbs. of dry gas per lb. of fuel - Lbs./Lb.
M = Lbs. moisture formed per lb. of fuel - Lbs./Lb.
T_g = Temperature of gas leaving stack - °F.
t_a = Temperature of air at inlet - °F.
1089.0 = A constant for net latent heat - BTU/Lb.
0.46 = Specific heat of water vapor for 1089.0 - BTU/Lb. - °F.

ASSUMPTIONS

Fuel analysis H = 11%
Calorific value of fuel = 13,500 BTU/Lb.
Specific heat of dry gas = 0.25 BTU/Lb. - °F.

METHOD OF SOLUTION

For air temperature - same for gas temperature

Max. diff. = 0.001 x 13,500 = 13.5 BTU/Lb.

Let h_x = true loss, t_x = true air temperature
h_y = measured loss, t_y = measured air temperature

Then

$$h_x - h_y = 13.5 = CO_p\,(t_y - t_x) + M\,(t_y - t_x)$$

$$t_y - t_x = \frac{13.5}{.25\,0 + .98}$$

VALUES CALCULATED FOR CURVES

Approx. CO_2 - %	0	Air - °F. $t_y - t_x$	Gas - °F. $T_x - T_y$
6	36.868	1.84	-
8	27.338	2.36	2.53
10	22.078	2.84	3.09
12	18.532	3.29	3.63
14	15.998	3.71	4.18
15	14.985	3.91	-
16	14.098	4.09	4.84

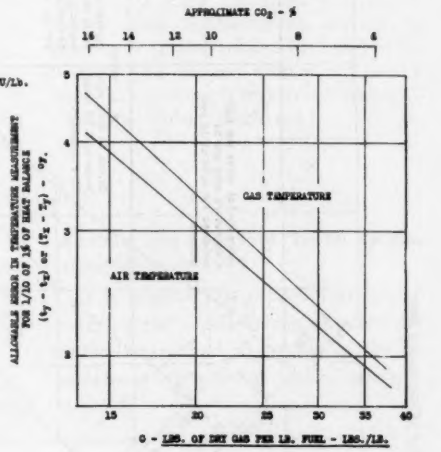

FIGURE 6.

GAS AND AIR TEMPERATURE MEASUREMENT, FIG. 6

The accuracy requirements for gas and air temperature measurements are, as shown, a function of the flow of dry gas. A device for measuring air temperature could be made universal for all normal conditions, while one for gas temperature would have to be designed almost specially for each operation. The stratification of gases in the stack required multiple temperature measurement to obtain the average. A difficult radiation problem also exists because the temperature sensing element is immersed in relatively hot stack gases with cold economizer tubes below and relatively cold stack walls for the device to "see." Very careful study of geometric and distribution considerations will be required to meet the accuracy required by Fig. 6.

HEAT BALANCE ITEM AFFECTED

Heat lost due to moisture in air
ASME long form items 103 + 104

$$h_L = cpw\ m\ (T_g - t_a)$$

h_L = Loss due to moisture in air - BTU/lb. fuel
cpw = Specific heat of water vapor in air - BTU/lb. - °F.
m = Pounds of moisture in air per lb. fuel - lbs./lb.
T_g = Temperature of gas leaving stack - °F.
t_a = Temperature of air at inlet (dry bulb) - °F.

ASSUMPTIONS

Fuel analysis C = 86% H = 11% S = 1%
Calorific value of fuel = 18,500 BTU/lb.
Specific heat of water vapor = 0.46 BTU/lb.- °F.
Carbon monoxide not formed.

METHOD OF SOLUTION

$$g = 7{,}000\ m/A$$

g = Grains of moisture per lb. dry air - gr./lb.
A = Lbs. of dry air per lb. fuel - lbs./lb.

$$h_L = \frac{0.46\ g\ A}{7{,}000}\ (T_g - t_a)$$

Let x = true
y = measured

$$h_x - h_y = 0.001 \times 18{,}500 = 18.5$$

$$18.5 = \frac{0.46\ A}{7{,}000}\ (T_g - t_a)\ (g_x - g_y)$$

$$(g_x - g_y) = \frac{18.5 \times 7{,}000}{0.46\ A\ (T_g - t_a)}$$

SOLUTIONS FOR ABOVE EQUATION

% CO_2	LBS.AIR LB. OIL A	$(g_x - g_y)$ FOR $(T_g - t_a)$		
		200	400	600
16	14.081	99.97	49.98	33.32
14	15.981	88.08	44.04	29.36
12	18.515	76.03	38.01	25.34
10	22.061	63.81	31.90	21.27

To cover this range of values for $(g_x - g_y)$ four curves are drawn, indicating allowable variations of 25, 50, 75 and 100 grains per lb. of dry air. Differences of wet bulb and dry bulb temperature were converted from 100% relative humidity curves up to 100°F. Above this temperature values were picked from the relative humidity corresponding to 300 grains per lb. of dry air. The Carrier Psychrometric chart was used.

ALLOWABLE ERROR IN WET BULB TEMPERATURE MEASUREMENT FOR 1/10 OF 1% HEAT BALANCE

ACCURACY OF PSYCHROMETRIC MEASUREMENT FOR 1/10 OF 1% HEAT BALANCE ERROR

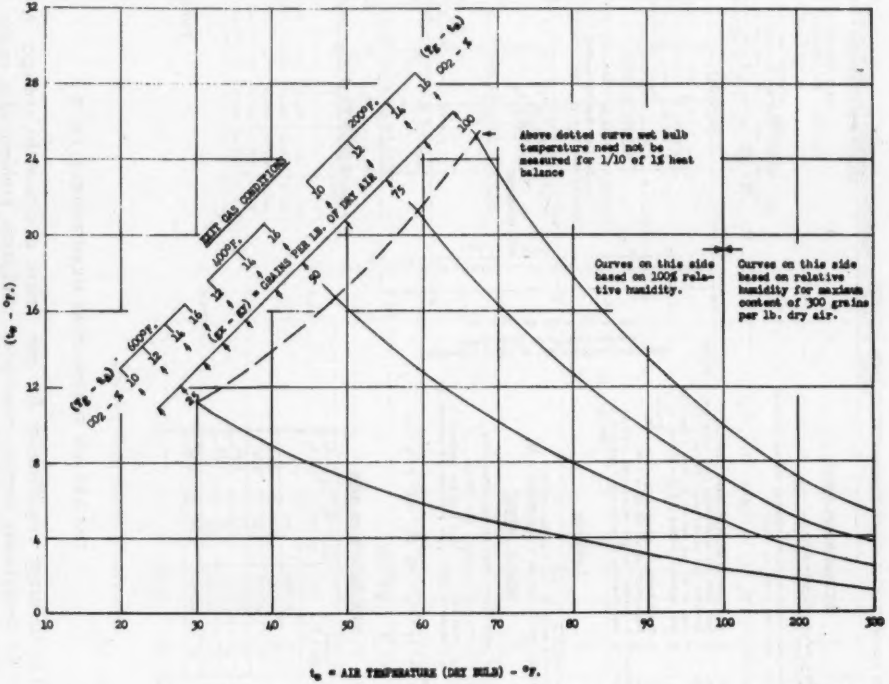

FIGURE 7.

PSYCHROMETRIC MEASUREMENT, FIG. 7

The large number of variables affecting the accuracy of this measurement prevents the plotting of a chart similar to the others for a simplified solution. Fig. 7 does point out several interesting indications. Under certain conditions it is unnecessary to take any psychrometric measurement to achieve the required accuracy. Greater exactness can be attained with a measuring device by placing it in the coldest part of the air system (the blower suction for example) than putting it in warmer locations (like the blower discharge).

CONCLUSIONS

This study of accuracy requirements, either by direct use of the charts or application of the methods on which they are based, to a certain degree provides a standard for measurements. It may be used as a basis for development of instrumentation because it serves to indicate which measurements are the least accurate and therefore to be concentrated upon.

It is planned to write future papers covering the actual instrumentation and methods used and the status of the development of the art of applied measurement.

Official U. S. Navy Photograph

DESTROYERS

BOILER WATERSIDE CLEANING

S. GREENBERG, J. L. SMITH AND A. HOWARTH

THE AUTHORS

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MR. S. GREENBERG graduated from Temple University in 1941 with B.S. degree in Chemistry. Worked at Industrial Test Laboratory of the Philadelphia Naval Shipyard from 1941 to 1947 as an analyst on light metal alloys. Started at Naval Boiler and Turbine Laboratory in 1947—Chemist in Application Branch of Petroleum Division of that Laboratory.

One of the constant problems associated with steam generation is formation of scale and sludge deposits on the water side of generating equipment. In recent years, their prevention and removal have become major problems because of higher operating pressures and temperatures. Slight deposits, once insignificant, now may result in tube failures. Despite advances in scale prevention, there still is need for effective scale removal, particularly in regions where make-up feed water contains large quantities of scale-forming substances. The Navy maintains strict control over boiler water treatment based on most recent developments in that field. Nevertheless, occasions do arise, either from emergency operating conditions or from inadequacy of treatment, when boilers must be taken off the line for scale or sludge removal.

In addition to requiring more effective scale prevention, many boilers of modern design cannot well be cleaned mechanically. Longer tubes with intricate bends and inaccessible circuits have made solvent cleaning the only practical cleaning method. Even in boilers of less recent design, mechanical cleaning

seldom completely removes scale. There are scales, particularly silicates, that are difficult to disintegrate by customarily used acids rendering mechanical cleaning essential. Loss of metal by acid attack has been an objection to acid cleaning, but this also is true to some extent with cutters used in mechanical cleaning. Labor charges and idle boiler time required for acid cleaning are so much less than with mechanical cleaning that this factor alone has induced many plants to adopt it. Today, therefore, scale removal by acid solvents is an established industrial procedure; penetration of crevices and depressions not reached by mechanical tools has resulted in more thorough cleaning. It is particularly effective on mill scale which mechanical cleaning will not remove. Mill scale can be removed from boiler parts by pickling before assembly, but that is not always done. Such scale is objectionable, especially in high pressure boilers, because of its interference with heat transfer as well as its accelerating influence on pitting and localized corrosion.

The Engineering Experiment Station, after conducting a survey of scales found in Navy boilers, compiled the tabulation, Figure 1, which shows that calcium sulphate, once the most troublesome scale, is well under control. There is considerable variation—both qualitative and quantitative—between deposits found in different boilers. Zinc, copper and lead oxides, calcium and magnesium phosphates, silica and calcium sulphate as well as oxides of iron—either Fe_3O_4 or Fe_2O_3—were found in practically all boilers in this survey.

Knowledge of chemical composition and physical structure of any scale is prerequisite to prescribing an acid treatment with any degree of certainty. For example, a scale composed almost entirely of calcium sulphate would be difficult to remove whereas one composed of calcium sulphate interspersed with calcium phosphate or carbonate might easily disintegrate as the more soluble scale constituents were dissolved. On the other hand, a stratified scale containing a layer of relatively insoluble and impervious scale such as a complex silicate may prevent the solvent from reaching layers of soluble scale beneath. Where microscopic and quantitative chemical analyses cannot be performed, much can be learned by observing the degree of solubility of scale in the solvent. Where operating conditions are constant, one thorough scale analysis may serve for many cleaning operations.

Sulphuric and hydrochloric acids are by far the most used scale removal solvents. Phosphoric acid was used by the German Navy and even lactic acid has been employed in special cases. Hydrochloric acid is recognized as the best solvent except in a relatively few special cases. The principal advantage of using this acid resides in its greater capacity for producing soluble chloride salts. A calcium carbonate scale cannot be readily dissolved in sulphuric acid because of low solubility; similarly, calcium phosphate is soluble only with difficulty in phosphoric acid. The fact that most inhibitors can be added to the concentrated hydrochloric acid without being decomposed, whereas the reverse is true with sulphuric, constitutes an advantage in favor of the former. Furthermore, danger of acid burns in handling is less with hydrochloric acid than sulphuric. Sulphuric acid is preferred by some for descaling high chromium alloys because of its lower rate of attack thereon. Considerable attention has been given phosphoric acid as a descaling solvent because of its lower attack on clean metal and the fact that, under properly controlled conditions, it leaves a rust-resistant coating on the metal surface. The slow reaction rate of inhibited phosphoric acid in the temperature range of 135-150° F. is one of the chief objections to using it for mill scale and rust removal.

Neither hydrochloric nor sulphuric acid is capable of removing some of the silicate scales found in navy boilers.

ANALYSES OF TYPICAL SCALES FROM NAVAL BOILERS

	Blr. 1	Blr. 2	Blr. 3	Blr. 4	Blr. 5	Blr. 6	Blr. 7	Blr. 8	Blr. 9	Blr. 10	Blr. 11
Fe_2O_3				26.98						0.8	61.7
Al_2O_3					12.4	5.10	9.55	2.60	22.80		
Fe_2O_3	10.59	11.40				23.13		20.60			
Fe_3O_4			19.33		15.36		26.93		19.45		
$Ca_3(PO_4)_2$	26.99	28.66	6.3		4.0	2.64	1.63	2.53	1.7		
$Mg_3(PO_4)_2$	5.39	6.03	0.55		5.89	9.06	0.8	5.93	4.33		
P_2O_5											1.4
PO_4				4.5							
$FePO_4$					19.02	9.22	15.65	21.89	13.02		
$CaCO_3$	0.68	0.55	21.55						1.2		
$Ca(OH)_2$			13.00							95.5	
SiO_2	1.58	2.67		6.89	10.19	5.63		16.4	10.29	0.6	1.84
$CaSiO_3$	21.25	18.74	23.3								
$CaSO_4$	0.94	0.94	8.12		4.25	2.88	2.68	0.75		1.11	
$BaSO_4$								1.84			
SO_4				27.89							
Mg				1.85							
Ca				17.5							
Na_2O					5.35						
ZnO	4.49	4.19	0.4		3.7	8.2	13.09	11.13	2.8		2.51
CuO	11.25	11.25	3.0	3.51	21.53	33.69	20.26	8.56	21.75		7.7
CaO											
PbO	0.7	1.0	0.8	0.55				3.55			
PbO_2					0.6	1.0	3.0		1.1		
NiO					0.39		2.15	0.37	0.72		
SnO								1.48			
Oil	0.89	0.87									
Other Organic	14.75	14.21									
Total Organic			4.43	7.0				2.16		0.6	21.96
H_2O											
Water Soluble					1.32						

FIGURE 1

When such scales are present in sufficient quantity and are of such physical structure as to resist disintegration by hydrochloric or sulphuric acid, they can be removed by supplementing the acid solvent with ammonium bifluoride at 1% to 2% concentration.

It is hardly necessary to mention that acid used in boiler scale removal must be treated to reduce its normal attack on steel. This is accomplished by addition of small quantities of "inhibitors," usually in the order of one percent or less of the concentrated acid used. Inhibitors are compounds which, when added to acid, reduce its attack upon clean metal but permit it actively on scale. Most inhibitors are organic polar compounds containing nitrogen, oxygen or sulphur and are varied in their chemical structure. They include amines, substituted ureas, aldehydes, pyridine and quinoline type ring compounds, coal tar products, and other substances. The important feature is that they are polar compounds.

Some of the most effective inhibitors are inorganic and organo-metallic compounds. They are objectionable for two reasons: they deposit or plate out metal on the boiler surface, and many of them are highly toxic. Inhibitors have long been used in acid pickling baths and there are many reliable brands on the market. There are various theories concerning the mechanism of their protective action. Discussion of them is beyond the scope of this paper, but it is generally agreed that the inhibitor molecule is attracted through its polar group to electrically-charged areas on the boiler metal, resulting from ferrous ions passing into solution. Attraction of sufficient polar molecules to the metal surface results in formation of a screen or blanket over metal areas and impedes acid attack to a small fraction of its normal rate, while solution of scale proceeds with little or no interference.

Inhibitors vary in effectiveness when used in different acids. Some are sufficiently effective in either hydrochloric or sulphuric acid; others are suited for one only. Some must be dissolved in concentrated acid, others in dilute acid. Also, their protection may vary with the type of steel or alloy involved, and there are limiting temperatures above which different inhibitors lose their effectiveness. All, or nearly all, inhibitors lose their effectiveness at temperatures around 180° F. It is advisable to work a safe distance below this temperature, at 135 to 155° F., unless manufacturers' recommendations restrict operation to a lower temperature. A wise precaution is to test the inhibited acid on a clean piece of steel before applying it to the boiler.

It is not unusual for water sides of boilers to be contaminated with oil as well as scale deposits. When excessive, its removal must be accomplished before attempting scale removal with an acid solvent. Boiling out with a 1% solution of soda ash, or tri-sodium phosphate and a wetting agent should remove it. When not excessive, acid removal of scale may be accomplished without a preliminary degreasing if a wetting agent is included in the inhibited acid; in fact, it is a good policy to include a wetting agent whether oil is present or not. Scale penetration will be aided; some authorities claim that pitting is minimized.

There are many published data on the rate of acid attack on boiler metal. This information, obtained by subjecting steel specimens to the action of various acids and inhibitors at controlled temperatures, is useful in evaluating acids and inhibitors and determining which metals are most readily attacked. However, the information is relative and should not be interpreted as the corrosion rate occurring in an actual acid cleaning operation.

The corrosion rate of stressed metal is greater than that of unstressed metal. Certain parts of a boiler—tube ends, for instance—are under considerable stress as a result of cold rolling and may be

EFFECT OF TYPE OF INHIBITOR AND ACID UPON THE CORROSION RATES OF VARIOUS TYPES OF STEEL

Inhibitor	Mild Steel		18%Cr-8%Ni		25%Cr-20%Ni		12% Chromium		4-6% Chrom-.5%Mo	
	HCl*	H_2SO_4*	HCl	H_2SO_4	HCl	H_2SO_4	HCl	H_2SO_4	HCl	H_2SO_4
No. 1	.011	.002	.005	.006	.010	.004	.037	.056	.006	.006
No. 4	.090	.006	—	—	.016	.004	.185	.013	.066	.008
No. 2	.011	.034	.009	.245	.014	.011	.072	1.735	.010	.261

* 10% HCl — 14% H_2SO_4 — 150° F.
Values represent weight loss in pounds/sq. ft./24 hours.

Fig. 2

expected to suffer greater attack than other parts of the boiler. Inhibitors are ineffective in retarding corrosion by dissolved ferric salts as expressed in the equation $2Fe^{+++} + Fe \rightarrow 3Fe^{++}$. Since laboratory corrosion tests utilize clean steel specimens, no ferric ions are introduced into the solution and this reaction cannot take place. In actual scale removal, however, where varying amounts of ferric ions are present as oxide, this reaction is very significant and sometimes requires a two-stage cleaning to prevent accumulation of high concentrations of ferric ions in the solvent. Figure 2 gives laboratory data on the solubility of some alloys in inhibited hydrochloric acid and sulphuric acids. Figure 3 shows the effect of ferric ions on the solubility of mild steel.

As might be expected, the corrosion rate of inhibited acids increases with concentration. Those ranging from 2% to 15%, therefore, are used. Naturally, the minimum concentration capable of producing satisfactory results should be employed. At 15% concentration, even in the presence of a good inhibitor, hy-

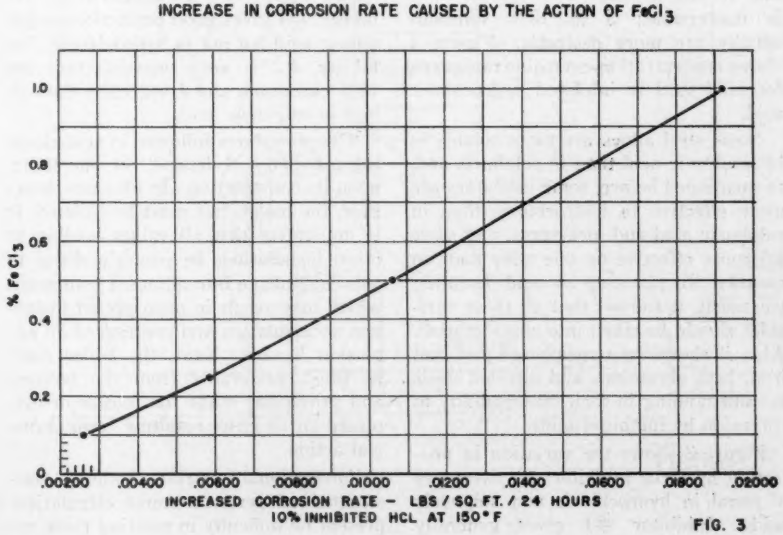


FIG. 3

EFFECT OF ACID CONCENTRATION (HCl) ON CORROSION RATE OF MILD STEEL USING INHIBITED HCl

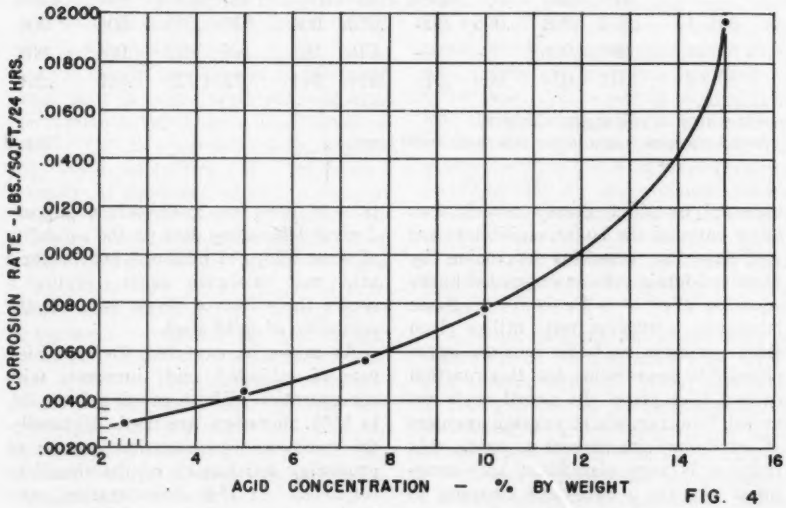


FIG. 4

drochloric acid becomes so corrosive that its use in other than special cases is inadvisable; 5 to 10% solutions usually are more desirable. Figure 4 shows concentration-corrosion rate curve for mild steel in inhibited hydrochloric acid.

Some steel alloys are more soluble in hydrochloric acid than in sulphuric and, as mentioned before, some inhibitors are more effective in hydrochloric than in sulphuric acid and vice-versa, and some are more effective on one alloy than on another. In planning an acid descaling treatment, it follows that all these variables should be taken into consideration. Also, it should be remembered that cast iron, 12% chromium, and nitrided steels are outstanding in their susceptibility to corrosion by inhibited acids.

Figure 2 shows the variation in protection by three inhibitors on five types of metal in hydrochloric and sulphuric acids. Inhibitor #1 gives generally good protection for all acids and all metals except 12% chromium alloy. Inhibitor #4 gives good protection in sulphuric acid but not in hydrochloric. Inhibitor #2 is very unsatisfactory for 12% chromium and 4-6% chromium alloys in sulphuric acid.

The procedures followed in acid cleaning a boiler will depend, for one thing, upon its construction. In all cases, however, the boiler first must be isolated. It is imperative that all valves leading to other installations be securely closed to prevent leakage into adjacent equipment which may result in unsuspected hydrogen accumulation and creation of an explosion hazard. Next, the boiler must be filled, preferably from the bottom, and provisions made for release of displaced air or gases resulting from chemical action.

Conventional marine boilers, constructed to permit natural circulation, present no difficulty in meeting these re-

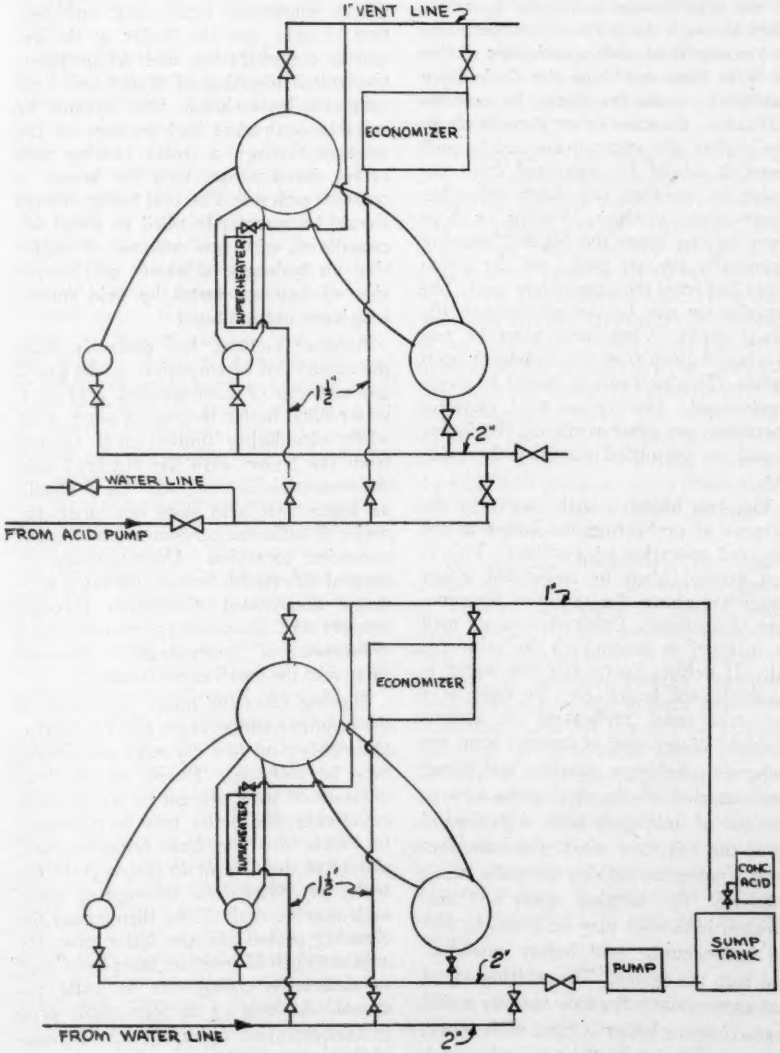

1" VENT LINE
ECONOMIZER
SUPERHEATER
1½"
2"
WATER LINE
FROM ACID PUMP
1"
ECONOMIZER
SUPERHEATER
1½"
2"
CONC. ACID
SUMP TANK
PUMP
FROM WATER LINE
2"

FIGURE 5

quirements. Many boilers of recent design require special filling and venting procedures. Natural circulation boilers of the type shown in Figure 5 can be filled through the bottom blowdown line and economizer and superheater drains by hose lines run from the dock down hatchways to the fire room. In some installations, the economizer extends above the level of the steam drum and in such cases it should be separated from the boiler by securing the check valve between these sections. Piping or hose must be run from the highest opening (generally the air cock) on the steam drum and from the economizer vent. The superheater can be vented through the steam drum. Vent lines must be run overboard away from any sparks or open flames. This precaution cannot be overemphasized. During an acid cleaning operation, no other work on the boiler should be permitted, particularly welding.

The first filling is with water, for the purpose of preheating the boiler to the required operating temperature. This is best accomplished by using hot water somewhat above the required temperature, if available. Otherwise, steam may be injected to accomplish the same result. If neither steam nor hot water is available, the boiler may be fired at a low rate until preheating is accomplished. Water now is drained from the boiler as quickly as possible and filling lines attached to the acid pump. Preparation of inhibited acid will depend upon the inhibitor used, the manufacturer's recommendations normally being followed. The wetting agent and ammonium bifluoride may be added to 20° Bé hydrochloric acid before introduction into the boiler. The wetting agent and ammonium bifluoride may be added at the time the boiler is filled with water, if the circulation method is to be used, or they may be added at the sump tank. They should not be mixed with concentrated sulfuric acid, and the ammonium bifluoride concentration entering the boiler should not exceed 2%.

The best acid filling procedure requires equipment facilitating introduction of acid into the boiler at the required concentration and temperature. Controlled blending of water and concentrated hydrochloric acid streams by suitable equipment and passage of the mixture through a steam heating unit before introduction into the boiler is common practice. The unit being cleaned should be completely filled to avoid accumulation of large volumes of explosive air-hydrogen mixtures and corrosion of exposed metal by acid fumes. which are not inhibited.

Another method, less desirable from the standpoint of corrosion, is the gradual addition of concentrated acid to a water-filled boiler through a sump tank while circulating diluted acid to and from the boiler until the required acid concentration is reached. Care should be taken that acid does not enter the boiler at sufficient concentration to cause excessive corrosion. Unfortunately, in natural circulation boilers, pumping produces accelerated circulation through headers and downcomers, resulting in a difference in concentration between these and the small tube circuits.

Having filled the boiler with acid at the required temperature and concentration, either of two common procedures may be followed. Based on previous analyses of scale present or on previous experience, the boiler may be permitted to "soak" for the time required completely to dissolve or to disintegrate the scale, or circulation through a sump tank may be maintained throughout the cleaning period. In the latter case, the acid strength of periodic samples is used to determine completion of scale removal. As long as an appreciable drop in concentration occurs, it may be concluded that acid consumption by the scale still is taking place. When several successive analyses show no change in concentration, cleaning action of the sol-

vent may be considered completed. Should the acid strength become too low for effective action, it may be restored by addition of more acid at the sump tank.

Some boilers of recent design cannot be filled and vented as simply as the above-mentioned type. Intricate tube circuits, normally filled by forced circulation, may entrap air and hydrogen, thus preventing complete filling. Expended acid with its higher gravity cannot settle in tube circuits and be replaced by stronger acid from the drums, and for the same reason cooled acid in exposed tubes cannot be replaced by warmer acid. Each type of boiler requires a separate analysis for venting and filling. Many of these boilers are designed for acid cleaning and are provided with acid-fill lines. In practically all cases, acid must be forced by pumping through the various circuits to flush-out accumulated hydrogen to a vented section and replace cold or spent acid in tube circuits. Since it is claimed that excessive circulation may result in serious corrosion, it should be kept to a minimum. Continuous circulation is unnecessary. One minute of pumping at half-hour intervals has been used at this Laboratory. Boiler design will, of course, influence pumping duration.

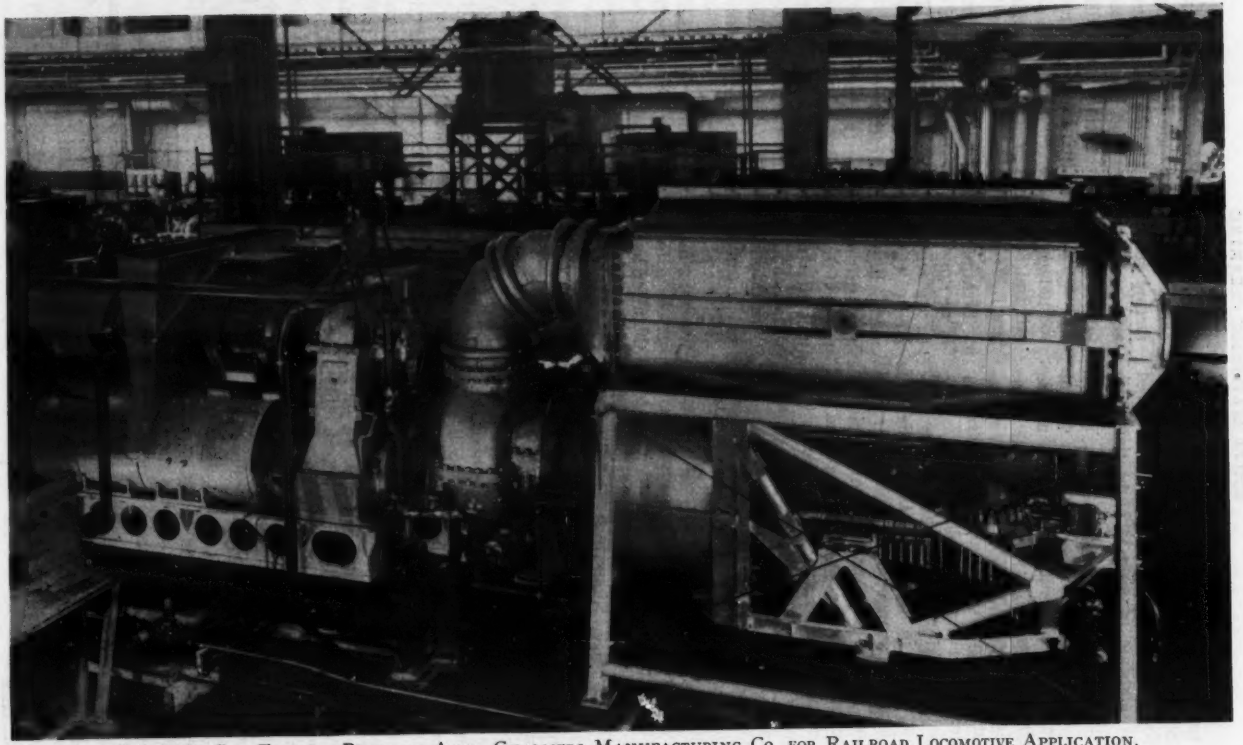
At the end of the cleaning period, acid is removed from the boiler through the drains and bottom blow down lines. Obviously, acid must not be dumped into the bilges but must be discharged overboard. As soon as emptied, the boiler is refilled with fresh water to rinse out traces of acid. Several rinsings are necessary to remove acid and soluble iron salts. In boilers equipped for circulation, it is advisable to circulate the rinse water in order to dilute and flush any circuits not completely drained through existing drain lines. When rinse water neither shows a precipitate of ferrous hydroxide upon treatment with sodium carbonate nor gives an acid reaction to methyl red indicator, the last traces of acid may be neutralized and the boiler protected against rusting by refilling with a solution containing 25 pounds of sodium dichromate, 50 pounds of soda ash and 50 pounds trisodium phosphate per 1,000 gallons of water.

Treatment of the boiler at this point is of utmost importance because of the strong tendency of the acid-treated surface to rust. Cardwell* has stated that metal loss from cleaned surfaces by after-rusting may be twice the loss attributed to the inhibited acid. He attributes after-rusting, in part, to the contact of air and acid fumes with the acid-treated boiler surface during draining and has investigated the effectiveness of displacing acid from the boiler with water or nitrogen, followed by one of a series of after-boil solutions. Among the after-boil solutions were dilute chromic acid, chromates, dilute phosphoric acid and phosphates.

As soon as practicable, the boiler should be fired at 50 psi for two hours to remove absorbed hydrogen from boiler metal. No cold working should be done on the boiler prior to this operation because of possible damage resulting from hydrogen embrittlement. After this treatment, the boiler is ready for normal operation. In some cases where a boiler contains a large quantity of scale and the soaking procedure is followed, piles of disintegrated scale particles may be found throughout the unit, and in those having complex circuits hours may be required to flush the scale to some accessible point where it can be removed manually.

The authors express their appreciation for the help given by Mr. R. C. Brierly in preparing this article.

* New Controls for Tube-Film Deposit—P. H. Cardwell—Power—July 1950.



4100 H.P. Gas Turbine Built by Allis Chalmers Manufacturing Co. for Railroad Locomotive Application.

FUTURE MACHINERY

A STAFF ARTICLE

With the publication of Mr. Huber's paper in the February issue it was hoped for a steady flow of articles on the gas turbine and its various elements. There has been a little, but much more is wanted in order that the Society may at least keep its members informed of what may be in the offing.

The following letter is the only direct comment which has been received on Huber. It is from Mr. James A. Fay, a member:

Editor
Journal of American Society of Naval Engineers
Bureau of Ships, Navy Department
Washington 25, D.C.
Dear Sir:

The article "Operational Stability of Free Piston Gasifiers" by R. Huber (Journal of A.S.N.E., May 1950) is a most welcome addition to what little literature has been published concerning this new type of power plant. It is, furthermore, an ingenious exposition of one of the many technically complicated facets of free piston gasifier design. Engineers interested in power plant development would benefit greatly by further published discussion of this fascinating and novel machine which are of the same technical excellence as this particular article.

A close study of the author's Figure 8 reveals an interesting conclusion in regard to the "operational stability" (as defined by the author). It was stated that, if the curves *a* are of lesser slope than the curve *d*, the machine is operationally stable. An examination of the construction of these curves shows that such is always the case regardless of the relative dimensions of the individual cylinders.

Curves *a* and *d* are influenced only by the power and compressor cylinders. Considering first the power cylinder, its contributions to the ordinates of *a* and *d* for a small change of the inner dead center position are nearly equal, since the net work output of the power cylinder would remain substantially constant for constant λ (air-fuel ratio). On the other hand, the contribution of the compressor cylinder to curve *a* is negative (reexpansion work decreases) but that to curve *d* is positive for a decreasing inner dead center position. As a consequence curve *d* is always steeper than *a* for a machine of the type illustrated irrespective of the cylinder capacities.

In view of these facts it is difficult to follow the author's conclusion that "as a result of an improper dimensioning of the various cylinder capacities involved, . . . unstable operation would result."

As a matter of fact, cylinder dimensions are chosen entirely from considerations other than stability of operation. It would indeed be unfortunate if the latter were not the case.

It would be interesting to outline the process whereby the cylinder dimensions are determined. First, a thermodynamic study of the "balanced" cycle is made, assuming reasonable values for the compression and diesel cycle thermal efficiencies, heat losses, pressure losses, etc. This would reveal the principal performance factors as a function of the pressure ratio: exhaust temperature, air-fuel ratio, and cycle efficiency. It would be found that the efficiency and output for a given size of machine increase with the exhaust temperature (and pressure ratio), and that the maximum values of the former are limited by permissible turbine inlet temperatures. Thus the "design point" of the gasifier would be fixed at a corresponding pressure ratio.

From these quantities the cylinder dimensions are determined in the following manner. For the design pressure ratio, a reasonable compressor volumetric efficiency is assumed (i.e., reasonable in view of the projected design of cylinder clearance volume and cylinder cooling) which, together with the compression efficiency and cooling effects, determines the volume of power cylinder scavenge air per unit compressor cylinder volume. Previous experience dictates a proper bore/stroke ratio and delivery ratio (volume of scavenge air to power cylinder displacement), thereby determining the dimensions of the power and compressor cylinders.

It should be noted that none of the aforementioned requirements to be met are the least bit liberal. Too low a delivery ratio, for example, will give poor scavenging, while too high a value is wasteful of air, resulting in low air excess and consequently poorer efficiency. In general, an efficient and compact power plant will not result from forfeiting any of these component requirements of the best obtainable efficiencies, low heat losses, and good proportioning (in light of present practices). The nub of the problem is thus how to secure these requirements through proper design rather than their relative importance in the design scheme.

Nothing has yet been said of the relative placement of the various cylinders and the mechanical arrangements of the machine components. These may be chosen in any manner which fits within the framework of the basic requirements and which the designer deems most appropriate for fulfilling them. Here is the greatest latitude in the design (and consequently its most controversial aspect) which may portend the success or failure of the machine. It appears to the writer that there are no conclusive arguments as to which arrangement of cylinders and parts is best; the fact may be that there are several equally good means of attaining the same end, each of which may have advantages peculiar to a special application. Nevertheless, a great finesse of design is essential if a reliable and efficient power plant is to result.

Returning to the subject of operational stability, the author envisages a somewhat special operating condition as a prerequisite to the stability study: a constant turbine inlet pressure. This would be true if a sufficiently large exhaust receiver were used, or if an automatic control were provided for maintaining a constant inlet pressure by varying the turbine inlet area (or bypassing gas). As the gasifier is most advantageous when made as compact as possible, and since variable inlet gas turbines are at present impracticable, it would appear that the problem of stability also involves the effect of varying exhaust receiver pressure (and also scavenge pressure.) As a consequence, it still remains to be shown how the corresponding receiver volumes affect the stability of the gasifier. Such a study

would be considerably more complicated than that already presented.

It should also be pointed out that there is always one unstable region of operation for the gasifier. As discussed in the first reference of the article, in reducing the output of the gasifier when operating with a turbine the stroke is shortened. When the outer dead center is moved inward sufficiently, the power cylinder scavenge ports will fail to open far enough to allow proper scavenging of the cylinder, and the gasifier will stall. Hence, at or near this operating condition, it is unstable to excitations which tend to decrease the stroke length, such as inadequate fuel supply, increased friction, valve breakage, etc.

The whole subject of free piston gasifier design is worthy of much more detailed discussion than it has hitherto been accorded. It is to be hoped that more articles of the technical calibre of that of Mr. Huber will be forthcoming in the near future.

Very truly yours,
James A. Fay

One enthusiast who prefers anonymity for the present has presented his views on the subject in the following remarks:

THE GAS TURBINE AND PREE PISTON GASIFIER

The spectacular development of the gas turbine is due to applications where the simplicity and light weight of the open cycle type were a godsend and its low thermal efficiency could easily be tolerated. In a turbocharger for instance, as long as the turbine could extract enough energy out of the normally wasted energy of engine exhaust gases to drive a supercharging blower, it was a step forward for the engine. In jet propulsion a turbine driven blower of a given weight of plant can produce a greater propelling thrust either through direct thrust of the turbine exhaust gases (turbojet) or in combination with a propeller (turbo-prop) than any other plant known today giving the plane a far superior speed, and even though its low thermal efficiency materially reduces its cruising radius the plant is being developed feverishly.

However, other applications demand better thermal efficiency and gas turbine theorists have shown that this can also be done—by raising the temperature of the gases. This will of course require either new heat-resisting materials or some way of cooling the turbine blades and much research is going on in both directions in Europe and in the United States.

Practical men see in the use of low-cost boiler fuel a more readily obtainable way to offset the low thermal efficiency. However, the ash resulting from combustion of this fuel brings with it mechanical erosion of turbine blading.

Furthermore, the high temperatures of combustion developed in the combustors of conventional gas turbines produce the highly corrosive vanadium pentoxide which so far can be controlled only by special fuels.

It would seem therefore that the success of the open cycle turbine will be limited by economics to its original application in turbochargers and jet propulsion even though engineers may find solutions to the perplexing problems on the way to its use in power plants which have to be efficient as well as simple and light.

The closed cycle turbine (Escher Wyss) in which combustion gases do not come in contact with turbine blading is making friends very slowly and its development is proceeding too cautiously to see whether it can and will be used for efficient power production.

The semi-closed cycle announced by Sulzer with much enthusiasm originally, apparently is not competitive except in very large sizes since they are understood to have announced that up to 6,000 BHP they will offer open cycle gas turbines.

On the other hand, the free piston gasifier-turbine combination is as efficient as the best diesel engine and produces no highly corrosive components in its exhaust. Millions of diesel engines in existence are the best proof that they can use more expensive diesel fuel and still remain highly competitive. Furthermore the newly developed modification of the diesel engine permitting it to burn natural gas with utmost efficiency and changeover to diesel fuel by pushing a button can easily be applied to the free piston gasifier and may open vast new fields of application.

All we need now is to develop the most reliable type of gasifier. The French, under direction of Pescara, the original inventor of the free piston idea, has already built seventeen different designs of free piston compressors and gasifiers in an effort to find the one that will live because of its superior reliability. Lima-Hamilton Corporation of Hamilton, Ohio recently delivered to the U.S. Naval Engineering Experiment Station of Annapolis, Maryland a twin gasifier unit supplying gas to a 650-KW turbine driven alternator. This plant will now undergo additional tests for endurance.

What is then a free piston gasifier? A highly supercharged diesel cylinder of the opposed piston type converting all of its power into compressed air direct, without the use of crankshaft, so that this air used for scavenging the power cylinder comes out of it mixed with hot exhaust gases and this mixture is then expanded in a simple conventional gas turbine. By eliminating the crankshaft and connecting rods and all the bearings, the unit becomes not only much lighter, and more compact, but also more reliable because lubrication worries are thereby also eliminated. An opposed piston design is inherently balanced perfectly hence gasifier requires no foundations and transmits no vibration to a ship's hull, thus reducing chances of discovery by listening devices. But most important of all, the gasifier inherits from its diesel power cylinder the superb efficiency of all diesel engines, i.e., a larger portion of the fuel's heat content is transmitted to the hot gases and then to the shaft of the turbine.

THE MARINE ENGINEER AND NAVAL ARCHITECT *of England discloses, in a general way, what is being done in England on new types of propelling machinery and on fuels for gas turbines. Two staff articles from the July, 1950, issue of that periodical are published below:*

NAVAL MACHINERY DEVELOPMENTS

The announcement on page 239 of the June issue, recording the placing of an unusual "machinery" contract by the Admiralty with Yarrow & Co. Ltd. in association with the English Electric Co. Ltd., is of great importance and technical interest. Not only does it mean that a very thorough investigation of current naval engineering practice in different parts of the world will be made

by the experts of these two firms but it pays practical tribute to the technical and manufacturing resources of one of our leading electrical equipment manufacturers in the field of the marine steam turbine for modern conditions. Those of us who are acquainted in some measure with those resources know that this policy of the Admiralty is admirable; and with the collaboration of a firm rich in naval experience, the results ultimately achieved will, we are confident, vindicate that policy up to the hilt. (While referring to this interesting point it is well to recall that the machinery for the new Blue Funnel steamships, briefly described in this Journal a month ago, is to be designed and manufactured by an equally eminent "land turbine" firm, Metropolitan Vickers). In Canada, it will further be recalled a frigate is building which will have Yarrow main machinery and condensers, both of English Electric design.

Of more immediate practical interest than the Yarrow-English collaboration and its ultimate results is the *Daring*-class destroyer machinery trials which have been carried out at the Pametrada research station. These trials have been of a thorough nature and have yielded valuable information, particularly in respect of maneuvering and astern trials. Fuel and water consumption tests of a very comprehensive character were carried out with the greatest care, special vibration and noise trials were made, elaborate temperature measurements were taken (including the temperatures in the bores of the hollow turbine rotors and in the tubes of the condenser) and altogether data of a kind and trustworthiness were gathered which will be of the greatest value in the future. The most valuable feature of these lengthy trials—quite beyond the scope of what might be termed commercial test-bed trials—was the confirmation of design calculations and other data; and so far as we are aware nothing quite so comprehensive has hitherto been attempted on a geared turbine installation—certainly not in this country.

With these investigations of naval geared turbines proceeding, and other development work on steam naval machinery being undertaken, it is natural that the onlooker should speculate as to the trend of naval machinery progress: will steam hold its own, and in what spheres? Is the naval gas turbine on or fairly near the threshold of big things? What of atomic power? A partial answer to the second part of the first of these questions was provided by Vice-Admiral M. M. Denny, speaking at the recent launch at Clydebank of the *Daring*-class destroyer *Diamond*. He expressed the belief that the *Darings* would be the last destroyers this country would build; smaller and lighter vessels "designed to deal with the submarine threat," would take the place of the destroyer, he thought. It is sad to contemplate that this useful type of craft, in the development and operation of which this country has played a great part, is obsolescent. The march of progress cannot be slowed, however, and there is little doubt that even the most modern destroyer is not the best weapon to tackle the submarine as it is now developing, with surface and submerged speeds of an order which were regarded as unlikely a few short years ago. For the propulsion of these small, fast "submarine destroyers" three types of machinery present possibilities: diesel engines, lightweight steam-turbines of the "gunboat" breed and gas turbines, possibly with variable-pitch propellers. In our view the first is an unlikely choice and lightweight steam turbines and water-tube boilers appear to offer the best possibilities for the immediate future. The gas turbine does, however, seem to have a promising ultimate field here, with light diesel engines for cruising. In the realm of the motor torpedo boat, too, the gas turbine has great possibilities. It is encouraging to know that

the Admiralty, Pametrada and several commercial firms are actively engaged on gas turbine development and research. The amount of activity in this sphere is great and embraces fuels and combustion, combustion chamber design, heat transfer and heat exchanger design, blading and other materials, the fouling (and, concomitantly, the easy removal of deposits) of blading and heat exchanger surfaces after periods of service, reduction gearing, and so on.

GAS TURBINES AND THE ADMIRALTY

The gas turbine equipment at present in use at the Admiralty Engineering Laboratory consists of a Metropolitan-Vickers Gatric engine similar to that installed in the pioneer *M.G.B.2009,* coupled to a Dynamatic brake, a pressurized combustion chamber testing rig and apparatus for the gravimetric chemical analysis of combustion gases. Air for the combustion rig is supplied by two Rolls-Royce Merlin petrol engines driving Griffon superchargers with a maximum output of 5 lb. per second each at 3½ atmospheres and by a Perkins diesel engine driving a Roots blower with an output of about 1¼ lb. per second at 5 lb. per sq. in. gauge. Patternator equipment for testing fuel sprayers is in course of installation.

Additional equipment on order includes a number of turbo-blower units which will be set up as self-supporting gas turbines for use in testing blade materials and two machines for carrying out fatigue tests on single blades at high temperatures. The supply of air for the combustion rig and other purposes will be increased by the installation of a second Roots blower, and a reciprocating compressor, both electrically driven. The latter will have a capacity of 0.64 pounds per second at 100 lb. per sq. in. gauge. Facilities are also being provided for brake-testing small turbines of up to 200 s.h.p. at speeds between 1,500 and 40,000 r.p.m.; a transmission dynamometer incorporating a 10 to 1 ratio epicyclic gear is on order; and an immediate requirement is being met in part by the conversion of a spare Merlin supercharger to an air brake. Accurate measurements of rotational speed will be secured by the use of a five-decade crystal-gated electronic counter.

The Gatric engine had been run for some 120 hours up to the end of 1949, using pool gas oil. This period included runs to establish the characteristics of the engine, and to improve the accuracy of temperature and speed measurement, a series of acceleration tests with extensive electronic recording of temperature, pressure, speed and fuel changes for guidance in the design of governor gear for a gas turbine-driven alternator, and finally experiments in washing the compressor blades with various liquids in attempts to recover the efficiency lost through deposition of atmospheric dirt. Running recently re-commenced after stripping and cleaning the engine and fitting a new design of combustion chamber. Following proving tests on the new chamber, the future programme includes work with high-temperature strain gauges to measure turbine blade vibration while running and operation with boiler fuel, the latter to extend the work already carried out by Metropolitan-Vickers on a similar engine. The combustion rig has up to the present been operated principally on kerosene, initially to develop satisfactory operating technique and instrumentation and latterly to provide data regarding the rate of oxidation of various blade materials in the combustion products of kerosene. These data are required for comparison with the behavior of similar blade samples when exposed to the combustion products of boiler fuel. The ultimate objective of work on the combustion rig,

Gatric engine and blade test turbines is to secure satisfactory operation of gas turbines on boiler fuels falling within the Admiralty specification. All this work indicates that the Admiralty engineers are determined to keep in the van with marine gas turbine progress; and the exploration in connection with the use of boiler fuel, and the information being collected concerning the probable length of operation between overhauls and the condition of blade surfaces, etc., after a period of sea service is likely to be of the greatest possible value. When a gas-turbine-engined vessel of war goes into normal service it will be a red letter day in the history of marine engineering ranking in importance with the advent of the *Cobra* and *Viper* half a century ago; and it is certain that this country will have done a great deal to hasten that day. It would be rash to say that we shall beat our American friends —in any case the installation of *M.G.B.-2009* can be claimed as the pioneer by the historians—but it is certain that the British effort will be a practical one of technical importance.

ULTIMATE IN MARINE PROPULSION?

Finally, we come to a matter of marine engineering speculation upon which we have touched on one or two occasions. We refer to atomic propulsion. A recent Press visit to the Ministry of Supply's atomic establishment near Didcot suggests that the great progress of the past two years brings this intriguing possibility nearer practical politics than many considered likely even a month ago. Rumors of remarkable submarine machinery developments have been passed around marine engineering circles during the past year and it has been known that some of the best marine engineering brains and submarine experience available anywhere were engaged on the problem. Sir John Cockcroft, director of research at Harwell, said something of this last month. A "mock-up" was shown of a possible nuclear propulsion arrangement for a submarine. This illustration appeared in several newspapers and will have been seen by some readers. Essentially the unit comprises (presumably) conventional steam turbines using steam generated in boilers taking heat for steam-raising from a nuclear reactor containing fissionable material. The pile would, of course, have to be lead-encased and there would be a water-filled screen between the heat-exchanger compartment and the boiler room. The gas circulating system involves the employment of special turbine-driven pumps and, at the present stage, it seems unlikely that the final choice of gas for circulation around the system has been made. Helium (which is chemically inert and would avoid corrosion problems in the plant) is an obvious possibility but it is understood that liquids (including liquid metals) are also being examined because of their good efficiency of heat transfer.

Clearly, the above brief note shows, we are likely to see serious efforts made in a marine propulsion field to which the application of the term revolutionary is to say the least justified. It is a grim commentary on current affairs that large sums and much thought are being expended today on what is popularly known as the atomic submarine. Machinery of this type, if successful, would enable a craft so propelled to remain at sea without refueling for very long periods indeed. Refuelling would probably be made at special jetties and would necessitate lifting part of the reactor shielding and the removal of the complete atomic pile, followed by replacement by one containing fresh uranium fuel rods. The prospect of such development is interesting, especially as it may reach the field of practical engineering

in about five years time. Most marine engineers will, however, be more concerned with the wider potentialities of this imagination-stirring development in the sphere of merchant ship propulsion. There seems little doubt that such machinery, with its additional plant, lead linings, etc., would be heavier than the conventional steam turbine-water-tube boiler combination. An additional 1,000 tons for a 100,000 s.h.p. was tentatively suggested by Sir John; but on the other hand a considerable load of fuel oil would be saved. Perhaps, therefore, these projects are not so Jules Verne-like as some engineers have thought. Young marine engineers, apprehensive about the possible inclusion of nuclear fission questions in future "ticket" examinations, can draw consolation from the thought that they will, when that day comes, be playing a part in the most revolutionary turn marine propulsion progress has taken.

* * * * *

Residual Fuels for Marine Gas Turbines

An extensive program of research work on behalf of the Admiralty is being carried out at the National Gas Turbine Establishment and elsewhere

A study of world conditions and the economics of oil production and consumption has led to early recognition that it will be necessary to burn residual grades of fuel oil in gas turbines at sea. In appreciation of this, the Admiralty as the Government department principally concerned with the marine application of the gas turbine, has undertaken an extensive study of the heavy fuel problem.

The basic research work is in general sponsored by the National Gas Turbine Establishment whilst the application of the results of this research to marine engines is sponsored by the Admiralty. Close contact is maintained with similar work being carried out under private enterprise. The field of study has been divided into six headings, each of which are briefly remarked upon below. Security considerations prevent any more detailed information being released at the present time.

FUEL CHARACTERISTICS

In order to evaluate the problem, a survey which aims at giving a comprehensive picture of the nature of the ash-forming constituents of crude oils from the various world sources is being carried out. Work is also in progress on the problem of developing economical and efficient methods of removing undesirable impurities from residual fuels prior to combustion.

ATOMIZATION

An extensive research programme is in progress to determine the factors affecting efficient atomization of viscous fuels, rig tests of various types of burner and tests on aircraft type gas turbine engines provide complementary information.

FUTURE MACHINERY

COMBUSTION

Cyclone chambers designed to remove ash from the products of combustion are under active development by N.G.T.E. More orthodox types of combustion chamber designed primarily for use with residual fuel are also to be tested. Some combustion work on aircraft type gas turbine engines has been carried out.

HEAT TRANSFER

A study of the radiation characteristics of heavy fuel flames and the means of evaluating flame tube temperatures by heat transfer calculations has been undertaken with particular reference to the elimination of "cold spots" upon which carbon deposits might form.

BLADE AND HEAT EXCHANGER FOULING

Tests on static blades are being carried out and the composition of deposits and their metallurgical effects are being studied. Aircraft type engines designed for operation of distillate fuel are being run for extended periods on residual fuel to obtain practical data on fouling effects under various conditions of flow. A study of the best means of removing deposits from blading and heat exchangers is contemplated.

MATERIALS

Work is in hand on the effects of the commoner types of impurities of residual fuel, viz: compounds of sulphur, sodium and vanadium upon the structure. The properties of the high temperature-resisting materials used in gas turbines. are also under close examination.

In addition specimen blades from static and engine fouling tests receive detailed metallurgical examination.

THE EDITOR WILL NOW AWAIT CRITICISM, DISCUSSION, AND NEW IDEAS.

U. S. Army Photograph

LANDING CRAFT ENGAGED IN PEACETIME EXERCISES.

THE TITANIUM PROGRAM AT THE U. S. NAVAL EXPERIMENT STATION

W. LEE WILLIAMS

THE AUTHOR

Received the degree of Bachelor of Science in Chemical Engineering in 1941 from Antioch College. During four of his student years he served under the cooperative plan as laboratorian in Physical Metallurgy at Battelle Memorial Institute. After graduation he became Metallurgist for the American Steel Abrasives Company. During the war he was commissioned in the Naval Reserve and served at the U. S. Naval Engineering Experiment Station. After discharge, he remained as a civilian metallurgist and became Assistant to the Superintendent of the Metallurgical Laboratory.

A previous article of which Mr. Williams was co-author appeared in the November 1948 issue of the JOURNAL.

INTRODUCTION

There is little doubt that titanium and its alloys will become important structural materials. Continued faith in this belief is reflected by the widespread activity of the metals industry in titanium developments. The race for position in the industry is becoming keener every day. Each producer is backing one or more production processes to keep some amount of his product before the eyes of potential consumers. Meanwhile, feverish activity is going on behind the scenes to develop improved materials at steadily lower costs.

Nearly everyone knows, at least in a general way, why titanium has created so much optimism. Foremost, of course, is the unique combination of properties unobtainable by other structural metals and alloys. Titanium is plentiful, light in weight, strong, and corrosion resistant. In addition, there are many other attractive characteristics, as well as a few undesirable ones. These will not be discussed in detail because they are beyond the scope of this article.

If titanium actually possesses such worthwhile properties, one may wonder why the metal is not seen now in everyday use. The principal reason, in combination with others, is the present high cost of the metal. There are two ways to reduce the price. First is an improvement in production techniques, especially the development of a continuous method to replace the present batch process. Second is the production of titanium on a large tonnage basis. The latter is a tail-chasing situation; mass production can't be had without a large market, and a large market won't develop until the price comes down. Furthermore, large investments in tonnage plants are a decidedly bad risk at pres-

ent because as yet no one is sure that his process will prove to be the most satisfactory and economical in the long run. In fact, there is every reason to believe that production methods now being developed will quickly render present equipment obsolete.

High prices are of greater concern in civilian goods than in military equipment. Therefore, the military organization holds promise of becoming the first large consumer of titanium. High strength, light weight considerations are of particular importance in aircraft, and the air forces are working quickly to incorporate titanium in their designs. Advantages would be less significant to the other military forces. They have remained considerably more price conscious and have tempered their research and development programs accordingly.

The bulk of the Bureau of Ships' investigative program on titanium has been carried out at the Engineering Experiment Station. The test program has been neither elaborate nor costly, but sufficient information has been gained to contribute significantly to our knowledge of titanium. In the early part of the program efforts were concentrated on determining the more common mechanical and physical properties. Such data later became abundant in the technical press as more and more laboratories undertook their own investigations. The Station then began to emphasize those fields in which it was especially well fitted to contribute. Particular emphasis was placed on the fatigue properties, the corrosion characteristics in marine environments, and the properties at temperatures associated with steam equipment. Except for the latter, sufficient information has been gained to draw some well-founded conclusions.

The Engineering Experiment Station has published very little of its data accumulated to date. However, it has been the policy of the Bureau of Ships to distribute the Station's reports to those engaged in titanium developments. Authors in these outside activities have published certain general conclusions based on the Station's work. For example, frequent mention has been made of the outstanding corrosion resistance of titanium in sea water. Oddly enough, very little actual test data have appeared in the press to substantiate the statement.

It seems appropriate at this time to present some of the Station's experimental data as a matter of public record. The information should demonstrate to the reader why titanium is holding high interest to those in the naval industry. No attempt will be made to record all the mass of data collected to date. Instead, the presentation will be limited to a bare minimum of statistics.

TYPES OF TITANIUM

There are several methods of winning titanium from the ore. Only one of these, the Kroll process, has been exploited by manufacturers interested in a tonnage product. The process involves the manufacture of titanium tetrachloride, which in turn is reduced by liquid magnesium to produce titanium sponge.

Starting with the sponge metal, there are a variety of techniques used to consolidate the titanium into ingots suitable for forging or rolling. Each technique has its advantages and disadvantages in relation to cost, size of ingot, homogeneity, the purity level sought in the final product, and the ease of fabricating by rolling, forging, tube drawing, etc. The relative merits of the different processes have not as yet been fully evaluated. However, so long as the cost is competitive, the consumer need be concerned only with the effects of the production process on the engineering properties of the material.

TABLE I—PRODUCTION TECHNIQUES, STARTING WITH SPONGE TITANIUM

	Technique of Consolidation	Impurities		
		C	O_2	N_2
	Powder Metallurgy Processes			
A	Grind sponge to powder, seal by welding in a metal sheath, hot roll or forge.	Low	Low	Low
B	Grind sponge to powder, compress, sinter in vacuum, suitable for small parts.	Low	Low	Low
C	Direct hot compression of sponge, suitable for small parts.	Low	Low	Low
	Melting Processes			
D	Induction melt in graphite	High	See note	
E	Arc melt in graphite	Med.	See note	
F	Arc melt in water cooled copper	Low	See note	

NOTE: Process D, E, and F can be done in vacuum for low oxygen and nitrogen contents, or in an inert atmosphere for medium gas contents. Some tungsten contamination may occur from the electrodes used in arc melting (E and F).

The importance of this was recognized by the Station. Consequently, the test program was laid out to include materials obtained from a variety of sources. The processes result in different impurity contents, of which carbon, oxygen and nitrogen are of the greatest interest. Table I gives very brief details of the types of titanium studied at the Station.

Even though the impurities are shown as low in some cases, all of these processes yield materials in which the impurities are significant. Indeed, commercially "pure" titanium is in reality an alloy of titanium and residual elements. The effects of the impurities are reflected by differences in many of the mechanical properties, such as the tensile properties. This is especially true for the metal in the dead soft or fully annealed condition, although a full anneal is seldom used for a finished product. It is important to note, however, that all these types of titanium respond to strengthening through cold working. If the materials are cold worked to the same tensile strength, many of the other properties are comparable. For many applications, therefore, the method of production is more of a cost and fabrication problem, and is of small importance from the standpoint of behavior in service. Exceptions to this do exist; for example, large differences are observed in the fatigue properties, as will be pointed out later.

Table II presents typical tensile test data to compare the various production processes. Appreciable differences are apparent between the annealed metals, and the differences would have been even more pronounced had full annealing been used in all cases. On the other hand, the properties become quite similar when sufficient cold work has been performed to bring each material to a tensile strength of 120,000 psi. The differences which do remain are most noticeable in the ductility measurements. The tabulated data are typical, but do not show normal variations between lots nor limits obtainable by each process.

The data shown in Tables I and II serve to describe in abbreviated fashion the types of titanium under study at the Station. It is not the purpose of this article to expand on these points, because detailed information has been published by other laboratories. It is well, then, to proceed with the experiments in which the Station has made more important contributions.

TABLE II—TYPICAL TENSILE TEST DATA
(Variations can be expected between lots)

	Tensile Properties	Type of Production Process					
		A	B	C	D	E	F
		Note 1	Note 2	Note 3	Note 4	Note 5	Note 5
Annealed	Tensile strength, psi	98000	82000	48000	94000	93000	76000
	Yield strength (.2%), psi	75000	62000	32000	80000	74000	62000
	Elongation in 2", %	15	28	32	20	27	32
Cold rolled to about 120,000 psi tensile strength	Tensile strength, psi	122000	122000	No Data	118000	120000	124000
	Yield strength (.2%), psi	107000	113000		107000	109000	—
	Elongation in 2", %	9	8		11	10	13

Note 1: As sheath rolled at 1475° F.
Note 2: As sintered at 1800° F.
Note 3: As hot compressed.
Note 4: Hot forged, annealed at 1300° F.
Note 5: Hot forged, annealing temperature unknown.

FATIGUE PROPERTIES

Many of the fatigue characteristics of titanium are unique among structural metals. A knowledge of these characteristics is essential for machinery applications in which cyclic stresses play such an important role. In some respects, too, the fatigue properties demonstrate more marked differences between the production processes than does any other mechanical property.

Fig. 1 is a collection of typical stress-cycle curves for flexural and torsional fatigue tests in air and for a corrosion-fatigue test in brackish Severn River water. Several production processes are represented, as well as different tensile strengths of the bar stocks from which the specimens were made. One of the flexural tests was made of a titanium base alloy with a nominal composition of 2½% chromium and 1% iron.

Let us consider first the flexural tests made in air. It is apparent that a wide range of endurance limits is obtained. In the present illustration they vary from 14,000 psi to 63,000 psi for the commercially "pure" titanium, and up to 71,000 psi for the alloy. One immediately wonders, therefore, what endurance properties can be relied upon should titanium be incorporated into machinery designs. This question resolves itself nicely with a further analysis which follows.

It is convenient to discuss the air flexure data as arranged in Table III. The endurance ratio shown in the last column is the ratio of the endurance limit to the tensile strength expressed in percentage. When such a ratio has

TABLE III—SUMMARY OF FLEXURAL FATIGUE TESTS IN AIR

Type	Production Method	Final Treatment	Tensile Strength, psi	Endurance Limit, psi	Endurance Ratio, % $\frac{\text{E.L.}}{\text{T.S.}}$ X100
A	Sheath rolled powder	Cold rolled 35%	97,800	30,000	31
C	Hot compressed sponge	As compressed	48,000	14,000	29
E	Arc melted in graphite	Hot forged	101,300	63,000	62
F	Arc melted in copper	Hot forged, annealed	75,800	43,000	57
F	Alloy, arc melted in copper	Hot forged, annealed	132,200	71,000	54

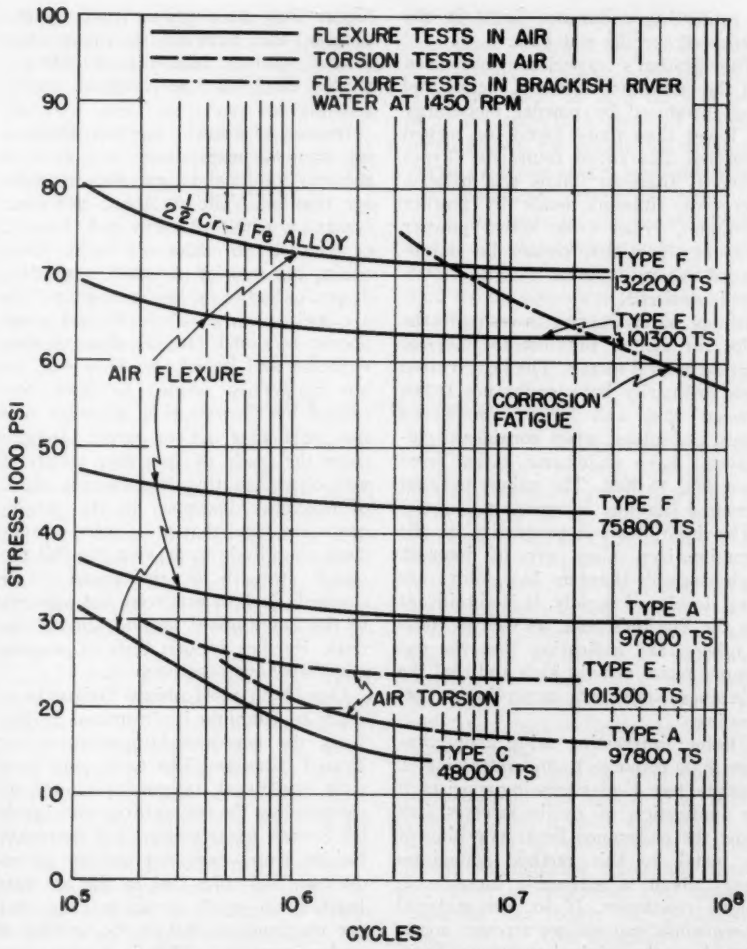


FIG. 1 FLEXURAL AND TORSIONAL FATIGUE CURVES FOR TITANIUM PRODUCED BY VARIOUS PROCESSES AND TREATED TO VARIOUS TENSILE STRENGTHS.

been determined for a material at one tensile strength, it becomes a useful criterion for estimating the endurance limit of the same material produced to a different strength. On this basis it appears that the tensile strength, and not the production process, is the important consideration in determining the fatigue properties, provided only that melting is involved in production. In fact, melted titanium is the only structural metal known which has an endurance limit consistently in excess of 50% of the tensile strength. This fact has been confirmed by other investigators, and a ratio of 50% seems a safe value

for estimating endurance limits in the absence of specific test data.

The Station's experience has been that the endurance ratios of metals and alloys produced by powder metallurgy are lower than those found for melted materials. The ratios found for Types A and C titanium follow this pattern. Therefore, titanium made by powder techniques, either from actual powder or sponge particles, cannot be recommended where superior fatigue resistance is desired.

It may be of interest to compare the ratios for melted titanium to those of other structural metals. The heat treated steels ordinarily have endurance ratios between 45% and 52%. Non-ferrous metals and alloys, when considered collectively, have endurance ratios from about 28% to 40%. The unique position of melted titanium is apparent.

The high flexural properties of the chromium-iron alloy are of interest. High strength titanium base alloys are being developed rapidly. It is significant that the Station's tests, as well as those of others, are indicating that the endurance ratios remain high and that the endurance limits are accordingly outstanding.

Another interesting thing about titanium is its response to understressing in a fatigue test. Understressing consists of the application of cyclic stresses just below the endurance limit. Working of the metal by this method sometimes brings about a noticeable increase in fatigue resistance. If so, the material subsequently can endure stresses somewhat above the original endurance limit. Annealed austenitic stainless steels exhibit this phenomenon to a marked extent. Titanium also is found to be highly responsive to understressing. For example, understressing tests were made of the Type E titanium, shown in Fig. 1 to have an endurance limit of 63,000 psi. Starting slightly below the endurance limit, 20 million stress cycles were applied to a specimen at each of several stress levels, each level being 2,000 psi higher than the previous level. By this process the titanium specimen was coaxed without failure to 80,000 psi, nearly 80% of the original tensile strength.

Insofar as known, the two alternating torsion curves shown in Fig. 1 are the only torsional fatigue data available for titanium. The torsional endurance limit of a metal ordinarily is 1/2 to 2/3 of the flexural endurance limit. Here, again, the powder metallurgy product, Type A, had very low properties. The arc melted metal, Type E, had much poorer torsional fatigue strength than expected and hoped for. However, the low properties seemed to have been caused by a production difficulty with this particular lot of metal. Judging from the mode of specimen failure, it was concluded that longitudinal planes of weakness developed in the forging operations, and that these were of sufficient magnitude to prevent the full torsional strength of the metal to be realized. Such defects were not apparent in the longitudinal tension and flexure tests. Further torsion tests of sounder materials have been planned.

One of the most unique fatigue properties of titanium is illustrated in Fig. 1 by the corrosion-fatigue curve for Type E titanium. The tests were made with the usual fatigue specimens by surrounding the test section with brackish Severn River water. The corrosion-fatigue curve does not exhibit an endurance limit like that in the air tests. Instead, the cyclic stress to cause failure continues to fall as the number of cycles increases. This is because corrosion is a time process. Cyclic stresses accelerate corrosion and cause the formation of very sharp corrosion pits. The sharp pits in turn accelerate fatigue by introducing stress concentrating notches.

The corrosion-fatigue test is useful for comparing materials so long as the specimen size, corrosive medium, and cycle frequency remain comparable. These conditions of test have been

standardized in the laboratory for a great many years; therefore some interesting comparisons can be made. It is noteworthy that heretofore two of the best structural alloys for resisting corrosion-fatigue in salt water were K-Monel and Navy Class 10 steel, the latter containing about 16% chromium and 2% nickel. In fact, it was this superior behavior that led to the use of these alloys for outboard shafting on PT boats. If the stress to cause failure in 50 million cycles is chosen as a basis for comparison, the materials line up about as follows:

K-Monel .....36,000 psi
Class 10 steel.....36,000 psi
Titanium .....60,000 psi

Titanium, then, is in a class by itself. It is the only high strength structural metal known for which the stress-cycle curve in a salt water corrosion-fatigue test approaches closely the stress-cycle curve for tests in air. Since a fatigue test is a very sensitive index of corrosion damage, the corrosion-fatigue data lend strong support to the claims of outstanding corrosion resistance in marine environments.

MARINE CORROSION PROPERTIES

Extensive tests have been performed by the Station to evaluate the corrosion resistance of titanium for marine applications. It was of interest to note that the production methods used in consolidating and fabricating the titanium had no noticeable effect on the corrosion properties. Therefore, the following discussion will not differentiate between the various types of metal.

As would be expected, the initial studies were made with laboratory type specimens. The results have been uniformly outstanding, so now the corrosion testing is being directed toward service or simulated service type tests. It is well to record here some of the results of the initial survey.

The Station has had little interest in the "beaker-type" corrosion test. Results so obtained are difficult to evaluate in terms of performance under the multitude of conditions met in service. Preference is given to a number of inexpensive, quick testing methods which enable the observer to predict with greater certainty the possible usefulness in many applications. Some of these will be described in the following paragraphs.

For structures which are not intended to handle sea water, but which are exposed to salt-laden air, the most satisfactory method of test is simply to expose panels in a coastline atmosphere. Tests of this type have been performed on many titanium panels. Exposure sites were located at 40 and 800 feet from the ocean at Kure Beach, N. C. Eighteen months produced absolutely no change in the appearance of the panels. Tensile tests of specimens cut from the panels showed no change in properties which might have resulted from microscopic cracking or intergranular penetration. No weight losses could be detected, even with specimens as large as 76 sq. in. exposed area.

Numerous types of tests have been performed in sea water. The first of these is called a quiet sea water exposure test. It is performed by mounting panels on insulated racks and immersing them in quiescent but constantly changing sea water at Wrightsville Beach, N. C. This location was chosen because of the much more severe fouling conditions than experienced at Kure Beach. The quiet sea water test gives information of three types: (1) the general corrosion resistance in relatively still water, (2) an indication of the toxic effect of the material to marine organisms, and (3) the susceptibility to pitting or crevice corrosion beneath the fouling.

Titanium panels exposed for eighteen months showed no visible change after

cleaning and no change of tensile properties as a result of the test. Unlike the stainless steels, there was no trace of pitting with the titanium. The original bright finish remained, although a weight *gain* of 0.0003 gm./sq. in. was observed on the average. The titanium showed no apparent toxic effect to marine organisms. Fig. 2 shows the extent of fouling which occurred to titanium specimens after only five weeks exposure. It is apparent that more attention must be given to antifouling measures if titanium is used in place of copper base alloys for equipment handling sea water. Continuous movement of the water, treatment with chemicals, or possibly treatment with hot water would be necessary to prevent excessive fouling.

Another test performed in sea water at Kure Beach, N. C. is known as the trough test. The name is derived from a wooden trough in which specimens are mounted for exposure to slowly moving water (2 to 4 ft./sec.). It is sufficient to state that insulated titanium is unaffected at this velocity. However, the trough is used also to test galvanic couples made up with dissimilar metals. Such information is of value because numerous cases exist in which different metals are joined together and exposed to a sea water electrolyte. Trim materials in bronze salt water valves make a good example.

FIG. 2—The extent of fouling on titanium panels exposed for five weeks in quiet sea water at Wrightsville Beach, N. C.

In a galvanic couple the corrosion rates computed on a unit area basis depend on the relative areas of the elements making up the couple. If a potential exists between the two metals, corrosion of the anode is accelerated. When couples are necessary in service applications, it is advantageous to have the anode much larger than the cathode so that the weight loss will be distributed over a wide area. A knowledge of this behavior is necessary in order to interpret correctly the results of galvanic tests made under specific conditions.

Table IV presents average results of galvanic corrosion tests in which titanium was used as one of the elements of the couple. The effect of accelerated corrosion is evident by comparison with the results for uncoupled specimens. Except for the uncoupled panel, no results

TABLE IV—AVERAGE RESULTS OF 145 DAY GALVANIC CORROSION TESTS IN SLOWLY MOVING SEA WATER

Material	Grams Weight Loss for a 10 sq. in. Panel		Accelerating Factor Due to Couple (1)
	Uncoupled	Coupled to Titanium	
Titanium	.0008	(2)	—
Copper	1.52	10.31	6.8
85Cu-15Ni	1.02	9.38	9.2
70Cu-30Ni (low iron)	.99	2.66	2.7
70Ni-30Cu (monel)	2.40	2.74	1.1
85Cu-15Zn (red brass)	1.90	7.84	4.1
96Cu-3Si-1Mn (Everdur)	2.10	14.16	6.7
18Cr-8Ni stainless steel	3.27	2.27	Retarded

(1) A function of test conditions. See text.
(2) Titanium coupled to the other metals was not affected.

are tabulated for titanium, because in all cases the weight changes of the titanium panels were so low as to be hardly measurable. A 1:1 area ratio was used for the panels making up each couple.

There are several points of interest in connection with the data in Table IV. First is the very low weight loss of the uncoupled titanium. The uncoupled 70Cu-30Ni alloy, commonly used for salt water piping and condenser tubing, was the nearest competitor to titanium, yet this alloy experienced a weight loss greater by some 1200 times. Another point of interest was the retarded corrosion rate of the 18-8 stainless steel when coupled to titanium. This might well be expected, because potential tests of materials immersed in sea water have shown passive 18-8 to have a potential somewhat lower than titanium. Monel has a potential in sea water very nearly equal to that of titanium, and this fact is reflected by the small difference in corrosion rate between the coupled and uncoupled monel specimens.

Fig. 3 is a photograph of the coupled specimens after test. It can be noted that most of the weight loss of the 18-8 steel specimens, as well as a considerable part of the loss on the monel pieces, has occurred near the support holes. This is a local pitting effect known by various names, but often called crevice corrosion. The name has been applied because the pitting usually occurs in crevices created by nearby parts or by some adhering foreign particle. Changes occur in the composition of the electrolyte within these crevices, and local attack can occur if water velocities are insufficient to flush out the stagnant water. A high susceptibility to this type of corrosion is the principal reason that stainless steel is seldom used in the presence of sea water. Titanium, on the other hand, seems to be completely resistant to corrosion by this mechanism.

Marine equipment is damaged frequently by another form of attack known as corrosion-erosion. Condenser tubes, piping systems and valves are the most common sources of trouble. The corrosion-erosion attack is associated with high water velocities and water turbulence. The damage can occur in two ways. First, high water velocity alone can cause a general acceleration of corrosion. Second, accelerated corrosion may occur locally in areas subject to turbulence from an interruption of streamline flow; this type is related indirectly to water velocity, because turbulence increases as the water velocity increases. The accelerated attack in both cases is caused by the eroding away of protective corrosion films, thereby constantly exposing fresh metal to the corrosive medium.

There are several useful tests to evaluate materials for resistance to corrosion-erosion damage. One of these is called a rotating disc test. The test is conducted by mounting a 5 in. diameter disc specimen on the end of a shaft and rotating the assembly in sea water at 1140 rpm. In a setup of this nature, the water velocity increases along the radius toward the periphery of the disc. For many materials there seems to be a critical velocity beyond which the protective corrosion product films are swept away. Accelerated corrosion then occurs in this area. By measuring the diameter of the intact film, it is possible to calculate this critical velocity. Further, useful information is gained by measuring the weight loss and the amount of thinning of the disc along the outer edge. Table V presents data of this sort for several materials used or proposed for use in piping and heat exchanger systems. The outstanding position of titanium is noteworthy.

A useful method to study the simultaneous effects of velocity and turbulence is a rotating disc test of somewhat different design. Specimens are mounted radially around the periphery of a micarta wheel, which is rotated in sea water to produce a desired water velocity. Compartive data are shown in Table VI for several materials tested in this

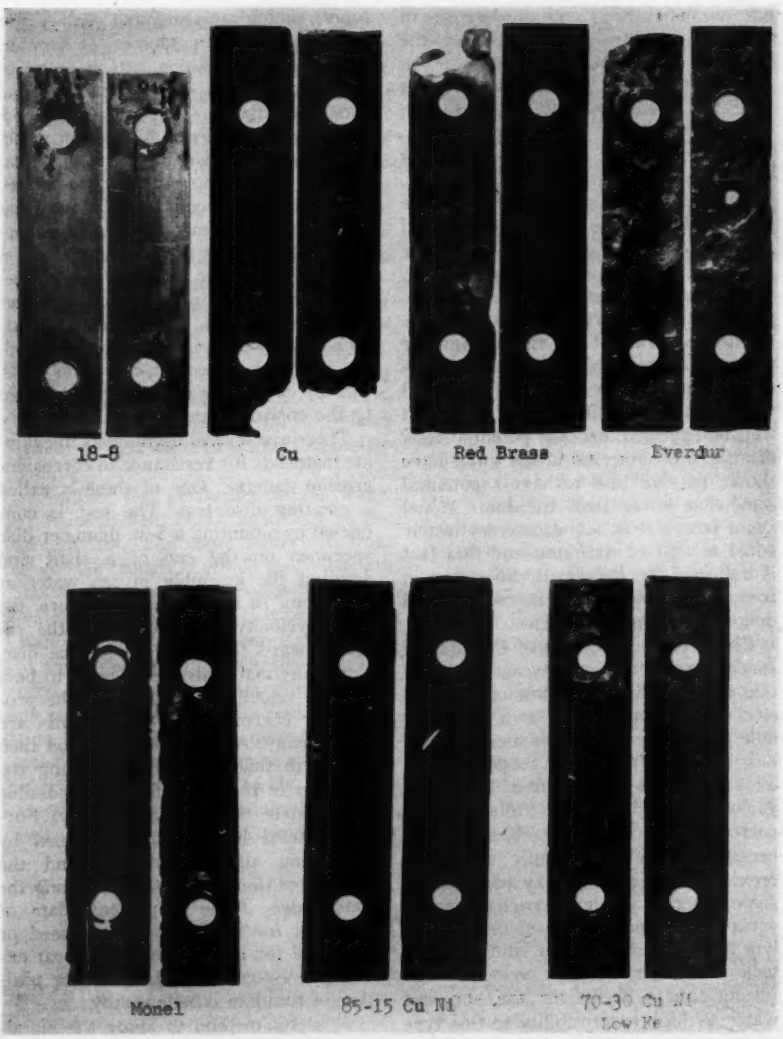


FIG. 3—Specimens of various materials after galvanic coupling to titanium and exposure to sea water for 145 days.

way for 60 days in 85° F. sea water. Here, again, titanium is outstanding in its resistance to corrosion-erosion. The data reported are for tests at 27 ft./sec. water velocity.

Titanium also seems to be resistant to stress corrosion in marine environments. Stress corrosion tests were made of ⅛" thick sheet specimens in brackish Severn River water. The specimens

TABLE V—RESULTS OF ROTATING DISC TESTS CONDUCTED IN 80° F SEA WATER FOR 60 DAYS. PERIPHERAL VELOCITY OF DISCS: 25 FT./SEC.

Material	Weight Loss, gm.	Critical Velocity, (1) ft./sec.	Loss in Thickness at Outer Edge, in.
Titanium	.05	25+	0.000
70Cu-30Ni-½Fe-1½Al	4.0	25+	0.003
70Cu-30Ni-½Fe	18.9	18	0.010
70Cu-30Ni	23.3	14	0.011
85Cu-15Ni	14.6	17	0.007
Red brass	9.6	19	0.009
Copper	22.4	18	0.012

(1) See text for significance.

were loaded in tension to 80% of the tensile strength. No failures developed in six months, so the specimens were removed and pulled in a tension machine. The tensile properties were identical before and after the stress corrosion exposure.

Quite a few other corrosion tests have been conducted on titanium in marine environments. However, the data which have been presented should be convincing enough of the uniformly outstanding behavior of titanium. Therefore, there seems to be no need to burden the reader with further statistics of this nature.

TABLE VI—RESULTS OF 60 DAY SEA WATER VELOCITY TESTS MADE AT 27 FT./SEC.

Material	Weight Loss, mg./sq. in.	Resistance Relative to Titanium, %
Titanium	.14	100.
70Ni-30Cu (monel)	61.4	.23
70Cu-30Ni-½Fe	198.	.07
18Cr-8Ni stainless steel	12.4(1)	1.13

(1) Most of weight loss through pitting.

CAVITATION RESISTANCE

The high order of corrosion resistance and the outstanding fatigue and corrosion-fatigue properties immediately raise the question as to the future of titanium for marine propeller applications. An excellence in these properties is important, especially for thin bladed propellers operating at high speeds. Forged titanium blades could be fabricated today, and the near future holds promise of successful casting techniques for titanium. Nevertheless, the advantages of titanium in high speed propellers could not be realized without good resistance to hydraulic cavitation.

Over the past few years the Station has evaluated nearly every alloy ever proposed for marine propeller applications. Successful hydraulic cavitation studies were made on contract with the Massachusetts Institute of Technology. The device employed was known as a

magnetostriction oscillator. Briefly, the setup consisted of an arrangement whereby a short ⅝ in. diameter cylindrical specimen was mounted on the end of a nickel tube which vibrated axially by magnetostriction. The specimen was immersed in Boston Harbor water during a test run. Measurements of weight losses were made as a function of time.

The magnetostriction method is cheap and quick. It does not duplicate service conditions, although experience has shown that a fairly good correlation is obtained with the actual behavior of propeller materials in service. The conditions employed in the test were as follows:

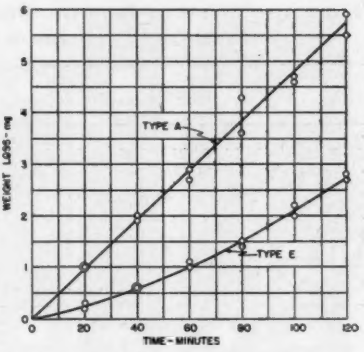


FIG. 4 — WEIGHT LOSS OF TITANIUM SPECIMENS TESTED FOR HYDRAULIC CAVITATION.

Amplitude of specimen vibration.....0.074 ± 0.004 mm
Vibration frequency .....6500 ± 200 cps
Static pressure .....Atmospheric
Water temperature .....25 ± 1° C.

Hydraulic cavitation apparently is a combination of corrosive and mechanical attack, with the latter perhaps dominating in so quick a test as this. It was not surprising, therefore, to find a difference between melted titanium (Type E) and titanium produced by a powder metallurgy technique (Type A). Fig. 4 shows results for each type over the two-hour period of the test. Fig. 5 is a photograph of the cavitated specimens.

Similar tests have been performed on many other alloys. It is of interest to select a few of these to compare with the titanium. Table VII gives such a comparison arranged on the basis of cavitation resistance relative to a standard brass control specimen. The alloys shown in the table have been used for propeller service or have been proposed for use partly on the basis of outstanding cavitation properties. The melted titanium was excelled only by the cast 16Cr - 6Ni steel, an alloy developed as a cavitation resistant material.

TABLE VII—COMPARATIVE HYDRAULIC CAVITATION DATA OF MATERIALS TESTED IN BOSTON HARBOR WATER. RESISTANCE RECORDED AS RELATIVE TO A BRASS CONTROL SPECIMEN.

Material	Relative Resistance
Brass control specimen	1.0
Manganese bronze	2.3
Ni-Cu-Si alloy	6.0
Forged 20Cr-10Ni steel	7.5
Titanium, Type A	9.6
Al-Ni-Fe bronze	14.
High tensile Al-Mn bronze ...	15.
Titanium, Type E	20.
Cast 16Cr-6Ni steel	28.

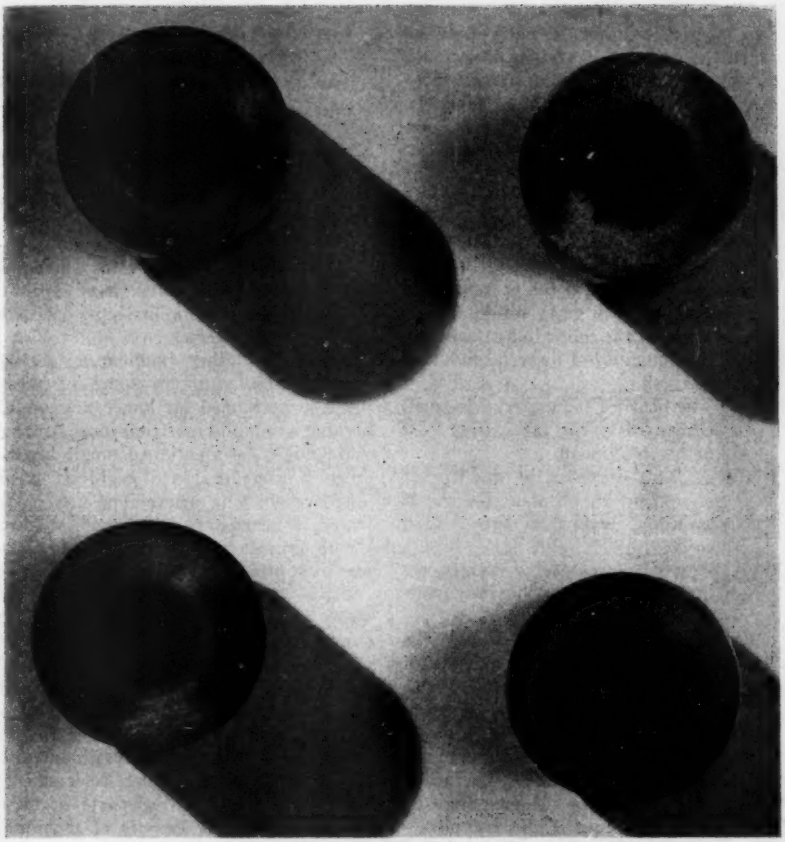


FIG. 5—Titanium hydraulic cavitation specimens after test.
Upper specimens: Type A material
Lower specimens: Type E material

IN CONCLUSION

The data which have been presented emphasized two phases of the Engineering Experiment Station's work with titanium, namely, fatigue and marine corrosion. Some unique and outstanding properties have been pointed out in each category. These fine properties, together with many others, are sufficient reason for the Navy to keep its attention focused on the titanium industry.

It is apparent that titanium could be used in a wide variety of applications if the metal were cheap and produced in large quantities. Unfortunately this is not the case today. It does not appear, either, that such conditions will prevail suddenly. A more reasonable expectation is that tonnages will increase and prices decrease gradually, going hand in hand with a gradual increase in the demand for the metal.

The military forces are in an excellent position to start the ball rolling toward the creation of consumer demand. Experiments at the Station have been planned with this in mind. Sufficient laboratory type tests have been performed to allow service and simulated service tests to get underway. In fact, the Station is actively engaged with such work at the present time.

The Station's current tests are based on the belief that limited use for titanium are economical even at the present price of the metal. Such uses would fall in one or more of the following categories:

(1) The quantity of material involved is small.
(2) The price of the material is small compared to the fabricating cost of the equipment.
(3) A large increase in the life of equipment would make the use of titanium economical regardless of price.
(4) The properties being sought require titanium as the only suitable material.

Getting down to specific cases, the Station is actively engaged in tests of titanium in the following applications:

(1) Wet exhaust mufflers for submarine diesel engines. Current designs have limited life, and replacement is a major operation.
(2) Meter discs for oil, gasoline and salt water meters. No completely satisfactory disc material has been found to date for suitable use in all three media.
(3) Condenser and heat exchanger tubes, especially where very high water velocities must be resisted by very thin tubes.
(4) Heat exchanger tubes for closed cycle engines. Excellent resistance is required to sea water on one side and to exhaust condensates on the other side.
(5) Antenna wires exposed to stack gases and marine atmospheres.
(6) Trim for salt water valves. Currently used materials, such as bronze and monel, have definite life limitations in high velocity water systems.

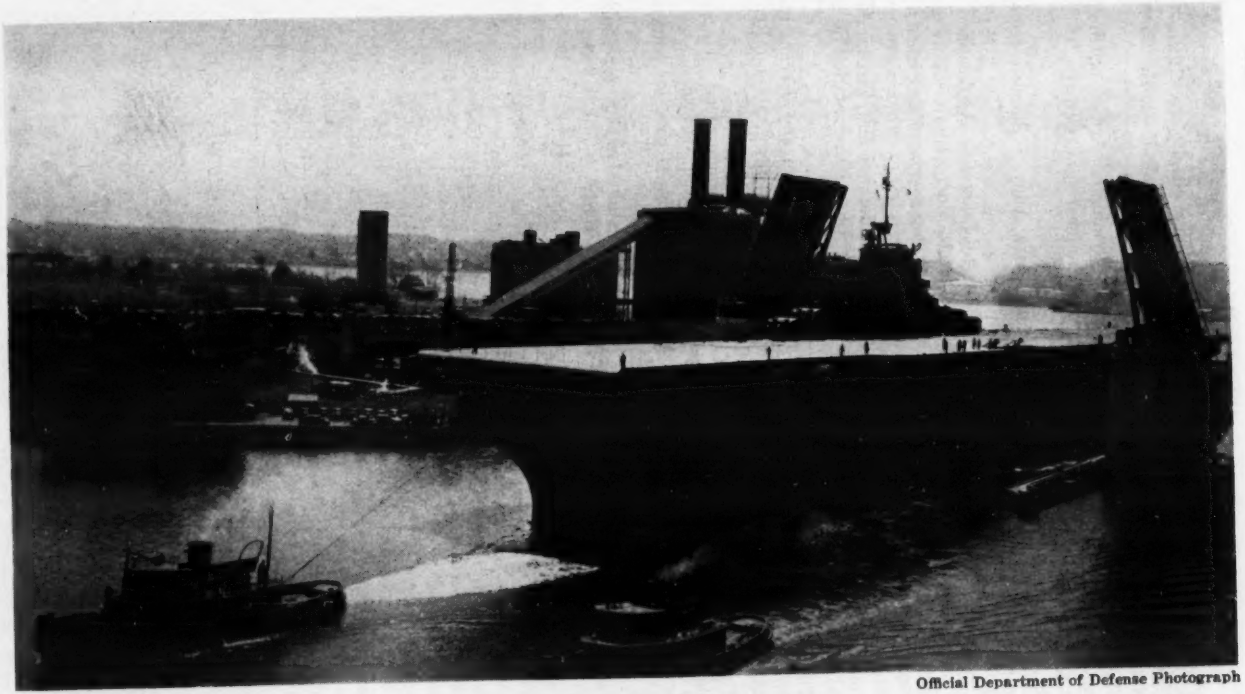
There are other applications being contemplated, although some of these must be postponed for lower prices and greater availability of titanium. Among these might be mentioned small highly stressed propellers, small highly stressed outboard shafting where exposure to sea water is necessary, and pump rods in which crevice corrosion around packings is a problem.

High temperature applications in steam equipment also are not being overlooked. The Station is making rapid progress in the study of the creep and stress-rupture properties of titanium and its alloys. Useful properties are obtainable at temperatures intermediate to those best suited to the aluminum and steel alloys. Of particular interest are applications for rotating parts in view of the low specific gravity of titanium. Steam erosion tests have been underway for some time to determine the usefulness of titanium and its alloys for turbine blading.

Bibliography

1. R. S. Dean and B. Silkes, "Metallic Titanium and Its Alloys," Bureau of Mines Information Circular 7381, Nov. 1946.
2. J. R. Long, "Fabrication of Titanium and Investigations of Titanium—Nickel Alloys in the Bureau of Mines Laboratories," Symposium, Office of Naval Research, Mar. 1949, pp 27-48.
3. "Titanium—A Special Progress Report," Product Engineering, Nov. 1949, pp. 130-152.

4. "Titanium and Titanium Alloys," Allegheny Ludlum Steel Corp., 1950.
5. "Technical Data and Properties of Titanium Metals," E. I. du Pont de Nemours & Company.
6. "Technical Information on Titanium Metal," Remington Arms Co., Inc.
7. "Symposium on Titanium," Industrial and Engineering Chemistry, Vol. 42, Feb. 1950, pp. 214-268.
8. Project RAND, "Titanium and Titanium Base Alloys," Batelle Memorial Institute, Contract W33-038.
9. W. Lee Williams, "Some Preliminary Tests to Determine Applications for Titanium," Symposium, Office of Naval Research, Mar. 1949, pp. 92-104.
10. "The Properties of Titanium Metal," U. S. N. Engineering Experiment Station Report C-3501, 19 Nov. 1948.
11. "The Corrosion and Mechanical Properties of Titanium and Zirconium at Normal Temperatures," U. S. N. Engineering Experiment Station Report C-3395; C-3501-B, 9 Feb. 1950.
12. "The Corrosion and Mechanical Properties of Titanium and Zirconium at Normal Temperatures," U. S. N. Engineering Experiment Station Report C-3395-B; C-3501-C, 2 Aug. 1950.
13. "Titanium Produced by Direct Hot Compression of Sponge Metal," U. S. N. Engineering Experiment Station Report 4L(4)066918, to be issued.
14. W. C. Schumb, H. Peters and L. H. Milligan, "A New Method for Studying Cavitation Erosion of Metals," Metals and Alloys, May 1937.
15. W. C. Stewart and W. L. Williams, "Investigation of Materials for Marine Propellers," Proc. ASTM, Vol. 46 (1946), pp. 836-845.



Official Department of Defense Photograph

AIRCRAFT CARRIER CLEARING FORE RIVER BRIDGE.

LIGHTS AND LAWS

CHARLES E. WILKENLOH

THE AUTHOR

Was born in New York City on the 24th of November 1906. Attended the public schools there, graduating Stuyvesant High School in 1925. Has engineering credits at Columbia University Extension, and is at present a student at the American University in Washington, D. C. Has worked in the field of electrical engineering most of his life and was at one time the laboratory manager for E. L. Cunningham Inc., and also was assistant to the factory engineer of the Arcturus Co.—both manufacturers and sellers of radio vacuum tubes. Came to the Design Division of the Bureau of Engineering (now Ships) in 1939 and started work on the design and development of ships' exterior signal systems, of which the navigational light system is a major part. This work brought him face to face with the "legalistics" involved in applying navigational lights to naval vessel construction. Is now recognized as the Bureau Authority on matters relating to the navigation lights and, in this capacity, attended the Congressional hearings for Public Law 239 (An act designed by the Judge Advocate General for the purpose of permitting the navy to deviate from the Rules of the Road under certain conditions) as advisor to the head of the Admiralty Section of Judge Advocate General. Also attended the meetings of the American Committee for Revision of the Rules of the Road as Bureau of Ships' representative and advisor to the chairman. Has been concerned with "Lights and Laws" for over ten years.

"The district judge said that without undertaking to find affirmatively why the lights (of the schooner) were not visible, he found simply that the steam-boat was in the exercise of due diligence, and that the lights were not capable of being seen, and that for that fact he relied much on the appearance and manner of the master of the steam-boat, which impressed him favorably . . . . "*, The quotation, taken out of context, is to be construed neither as derogatory to the court nor critical of the decision rendered, but to emphasize the fact that, apparently the judge had no better criteria than the appearance and manner of a witness for determining the "capability" of a green side light to be seen.

It is quite probable that the delegates to the International Marine Conference of 1889 considered legal decisions of this character. The "Reports of Committees" of that conference contain seven resolutions relating to the optical characteristics of navigation lights. Had the material contained in these resolutions been available to the courts of 1880 and 1881, which heard the case cited above, a very different kind of decision may have resulted. Perhaps we would be free of the admonition, derived from another decision about lights, equally questionable and more far reaching in its effect, the case of Clendenen v. The Alhambra†. that: "In practice we can at least be sure that even a reflected

* The Narragansette, 1 Fed 918 (1891)
† 4 Fed 86

glow of these (side) lights is not visible from our stem, and that within a reasonable distance ahead—perhaps a ship length—both (side) lights will show when our range lights are exactly in line‡." Resolution (8) of the International Marine Conference of 1889 states that, "The side lights should be so screened as to prevent the most convergent rays of the lights being seen across the bows more than half a point," a much more reasonable requirement than that expressed in all the major sets of rules relating to side lights, as will be shown later.

Tho the United States delegates in 1889 recommended that these seven resolutions, "be enacted as laws and embodied at once in the instructions now issued to inspectors of steam vessels . . . . ," they do not appear as yet in the rules of the road. In 1950, 60 years later, the courts still lack the kind of rules they should have with respect to the characteristics of navigational lights.

Comparisons of the sets of "Rules of the Road" have been published in numerous places at numerous times. The United States Coast Guard's profusely illustrated, "Comparative Rules of the Road and How to Obey Them" is probably the best of the more recent booklets on the subject. A glance thru its pages points up the argument that there are inconsistencies among the rules, and even within a set of rules. On the "Western Rivers" for example when you see an "amber" light, is it a tow coming toward you or is somebody's whistle blowing its head off*? Tho the International, U.S. Inland, and Great Lakes Rules require one-mile visibility for the anchor light(s), the Western Rivers require two-mile visibility, and the Panama Canal Zone three miles. The Great Lakes Rules require but three-mile visibility for the range light, all other rules require five miles. In the Western Rivers, a "river-type steam vessel," may carry side lights visible forward, aft, and abeam on their respective sides, all other rules require that the lights be visible from "right ahead to two points abaft the beam." There are of course many similarities in the various rules regarding lights and, tho these are expressed in a variety of language, there is much common ground for consolidation of the regulations into one code.

Law is the frame which supports and gives form to the Rules of the Road. An intelligent survey of the rules requires therefore at least a general knowledge of the legal structure. Two types of systems of law are involved. Statutory law, which is the basic legislation of the Congress of the United States, and administrative law, which comprises the rules and regulations established by an agency of the government to implement the statutes. Generally, statutory law is substantive in nature, it contains the substance or basic elements from which the intent of the Congress is to be projected. Administrative law is regulatory. It is the refinement and enforcement of the statute. Administrative law must not be in conflict with the statute it administers, neither should it add to the basic requirements of the statute. The Motorboat Act of April 25, 1940 is a good example of recent statutory law. Its "flag," "54 stat. 163; 46 U.S.C. 526" identifies it as a statute to be found in volume 54 page 163 of the Statutes or in volume 46 page 526 of the United States Code. The United States Coast Guard is the agency designated to administer the Motorboat Act. There is probably no better way to explain the legal position of the Coast Guard in this matter than to repeat Section 24.1 Part 24, Title 46 CFR (Code of Federal Regulations). "Basis and purpose of regulations.—By virtue of the authority vested in the Commandant of the Coast Guard under section 101 of the Reorganization Plan No. 3 of 1946

‡ The Rules of the Nautical Road—Farwell—Pg. 113.
* Compare Sect. 95.21 and Sec. 95.29 Western Rivers Rules.

(11FR (Federal Reporter) 7875) and the Act of April 25, 1940 (54 Stat. 163-167; 46 U.S.C. 526-526t), the regulations in Parts 24 to 28 inclusive, are prescribed to provide minimum safety requirements for both small boats and certain motor vessels while operating on the navigable waters of the United States in accordance with the intent of the statute and to obtain its correct and uniform administration." In order to "obtain correct and uniform administration" the Coast Guard promulgates regulations which amplify the Motorboat Act by prescribing among other things, the types and sizes of lenses, the construction of the light unit, the location of the illuminant, and the procedure for obtaining Coast Guard approval of this equipment.

There are at present several statutes and several sets of regulations which apply to navigation lights, and several government agencies devising and enforcing "rules." There are also legal precedents, which, in many situations, have the force or effect of law. Under statutory legislation known as the River and Harbor Act of August 8, 1917, the omnipresent Corps of Engineers, establishes and administers regulations regarding the navigation lights of certain types of vessels performing particular tasks in specified areas. Under the authority of a legal instrument, known as an "Executive Order" the Governor of the Panama Canal Zone prescribes regulations "to make effective" the Executive Order.

Summarizing the legal structure: the rules relating to lights (and the associated rules of navigation) are based in Acts of Congress generally known as statutory law. These Acts recite the intent of Congress and authorize certain government agencies to establish and enforce regulations and procedures, which become the administrative law, for the purpose of implementing and making effective, the Acts. In addition, certain legal precedents, and "executive orders," impinge on the rules of the road.

The statutes, as they affect lights, state the requirements in basic terms. This is customary practice in writing substantive legislation concerning technical matters. If, however, the regulations fail to provide the technical modifications required for the practical application of the statutes then a wide range of arbitrary conceptions of the meaning of the statutory terminology ensues. In the case of lights the omission of standards and limits of measurement from the regulations leaves all concerned without scientifically established legal criteria for using, judging, making, or installing ships' navigational lights.*

In order to establish specifications for the performance of certain navigational lights, experimental work, in which the writer participated, was undertaken. As a result of this work the trend of performance of a conventional light in terms of angle of arc and distance in linear measure has been determined. It is generally admitted that the screened lights of usual design show well outside the prescribed arc—the experiments indicate how much, and where. Tho no attempt was made to establish criteria for use in the legal evaluation of a light, the material collected can well be applied in formulating pertinent regulations for navigational lights.

The rules relating to lights include four measurable factors; (1) Arc of visibility, (2) distance at which the light is to be visible, (3) color and (4) spatial relationship (to another light or lights and in height above a datum plane). Stated in the language of the rules these factors appear in such form as; "an arc of the horizon of ten points of the compass . . . . from right ahead to two points abaft the beam," "visible at a distance of at least two

* It is notable that certain parts of the Motorboat Regulations contain first steps in this direction.

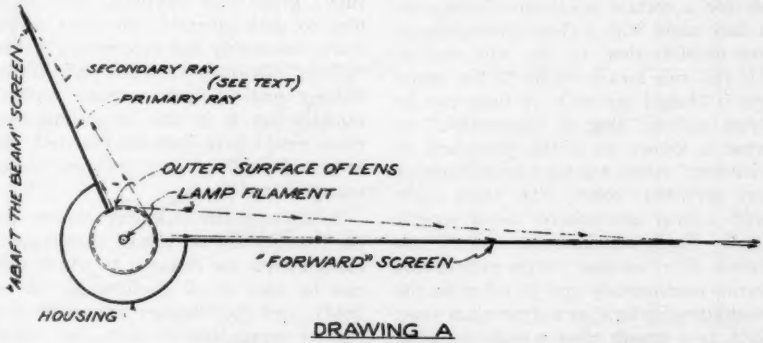
miles" (on a dark night with a clear atmosphere), "red," "the vertical distance (between lights) shall be less than the horizontal distance," and, "not less than twenty feet above the hull." When casually considered, the general nature of the existing rules appear to be sufficient. However, when one becomes concerned with manufacturing the light, locating it on a vessel, or establishing its legal status, the inadequacy of such broad specification comes sharply into focus!

As it involves considerations of range of visibility, color, and screening both ahead and abaft the beam, the sidelight provides a good subject for analyses. According to the rules these lights must, (1) show an unbroken light over an arc of the horizon of ten points of the compass from right ahead to two points abaft the beam, (2) be colored green on the port side and red on the starboard, (3) be visible at a distance of at least two miles (on a dark night with a clear atmosphere), (4) be fitted with inboard screens projecting at least three feet forward from the light and, (5) be so located on the vessel or so screened that a man standing in the bow cannot see either light.

An empirical optical performance test was set up to determine, on a quantitative basis, the degree of conformance with the rules which could be attained by a conventional sidelight, carefully designed to comply with the rules. The general constructional arrangement of such a light is shown and described in drawing A. The light was set up on a goniometer and observed from various distances ranging from three miles to a few feet. The arc of visibility of the light at various close-in distances is plotted on drawing B. At the long distances, two miles for example, the arc of visibility is very close to the required 112½ degrees, exceeding the limits by not more than one degree. At about 1000 yards, however, the arc of visibility begins to increase until the light shows, from the ahead position, some five degrees "across the bow," and seven degrees past the "2 points abaft the beam" line, at 400 yards and 200 yards respectively. Increase of the arc of visibility with decrease in distance of observation is an inherent characteristic of a conventional screened navigational light. Any optical system composed of a small light source within a Fresnal lens and with external screens will produce a similar light pattern. The reason for this is that such a system incorporates several sources of light; (1) the light from the filament (or wick) which, when viewed from a distance of a few yards, is seen on the lens surface as a vertical strip of very intense light, which can be termed "primary," (2) the light from the lens other than from the bright strip, or "secondary," (3) light reflected from the screen surfaces or "tertiary." The light which is seen at the maximum distances is that from the primary source. It can be screened to close tolerances in the arc of visibility. The light from the lens (other than that from the bright strip) is visible up to about 1000 yards and the arc thru which it can be seen is a function of filament brightness, lens diameter, color, thickness, and light transmission factor, and the screen length and its position with respect to the filament. The pattern of this secondary light, for the unit observed, is shown on drawing B. It will vary quantitatively for variations of conventional design but the shape is typical. Reflected light from the screen surfaces will materially increase the total arc of visibility, especially at the closer ranges. Tests made on a conventional type of side light indicate that rays reflected from the red, or green, screen surfaces are visible thru an arc 180 degrees. Painting the screens with a black glossy paint reduced this angle as much as 50 degrees.

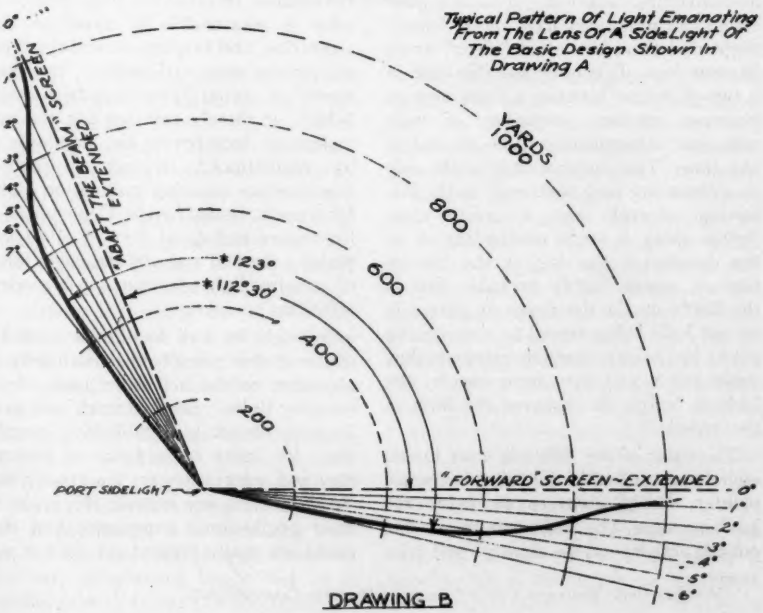
The tests referred to above were made with side lights designed to minimize the angle and the area outside the pre-

PLAN VIEW (BASIC) OF SIDELIGHT TESTED
This Light Is An Integral Unit. Screens, Lens, Lamp Socket, Housing, And Mounting Base Are Factory Assembled. Note The Location Of The Lamp Filament With Respect To The Screens, The Extension Of The Screens Close To The Lens Surface, And The Proportional Relationship Between Screen Lengths And Lens Diameter. The Screens Have Glossy Black Surfaces.



DRAWING A

Typical Pattern Of Light Emanating From The Lens Of A Sidelight Of The Basic Design Shown In Drawing A



DRAWING B

scribed limit of 112½ degrees at which light, direct or reflected, is visible. Consider what happens when a large lens, say ten inches in diameter, is placed in a "box" so that the point of intersection of the screens is outside the periphery of the lens and the screens are painted a color which reflects a large amount of the light!

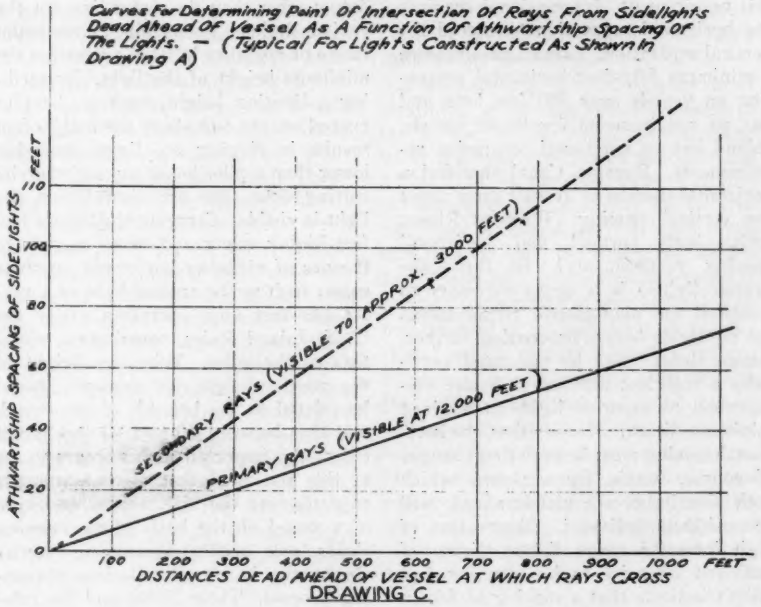
The requirement that the light be visible for a certain minimum distance on a dark night with a clear atmosphere is oversimplification to the *n*th degree. (If this rule means visible to the naked eye it should say so.) A light can be "just visible," that is, "detectable," or what is known as at the "threshold of visibility" without being recognizable as any particular color. The "dark night with a clear atmosphere" never repeats itself. Such standards are much too broad. The "content" of the atmosphere varies continuously and its effect on the visibility of a light at any previous time, such as a month after a collision, must be conjecture. There might be an appreciable tho unnoticed haze on a "clear" night and there are often "clear" areas in some fogs. It is quite possible that, in a two-mile line between a light and an observer, various conditions of hazy and clear atmosphere will be present at any time. The shortcomings of the rule as written are well portrayed in the following excerpt from a recent case, "while there is some uncertainty as to the density of the fog at the precise time, it seems highly probable that if the lights on the destroyer (a privately owned hulk being towed to a scrapping yard) had been reasonably adequate they could and would have been seen by the lookout before he observed the hulk of the vessel."*

The color of the lights is most inadequately prescribed in the rules. No house painter would contract to paint the kitchen white, the bathroom green, the outside amber, and the shutters and trim red. The penchant of housewives for just precisely such and such a shade or tint of these and other colors has become a standard theme for jokesters and cartoonists. Why should we be less exacting about specifying the colors of navigational lights? A cursory inspection of a large stock of navigation light glassware (lenses and globes) revealed reds ranging from orange, thru pink, to deep ruby; green was anything from baby blue to dark emerald; the clear glassware, commonly but erroneously called "white," obviously varied in light transmitting quality; there were no "amber" samples but it is safe to assume that these would have included greenish yellow, light yellow and certainly some orange hues!

It has been shown by experiment that the "quality" of the signal colors materially affects the distance at which they can be seen at all (achromatic threshold), and the distance at which they can be recognized as particular colors (chromatic threshold). The quality of color is measurable in terms of hue, saturation, and brightness, and the criteria for the most satisfactory "measurements" of signal lights have been established. It merely remains for the rule makers to incorporate the standards in the regulations! In fact a proposed specification covering navigation lights for vessels, issued by the Department of Commerce and dated April 9, 1941, explains a method and sets the color limits of running light glassware in a modern scientific manner.

It might be well to digress from the theme at this point to discuss briefly an objection to the scientific approach in defining lights. Some seamen and some lawyers object to establishing regulations for lights in the terms of photometry and colorimetry on the ground that these subjects are outside the realm of their professional experience and they could not really understand what it was

* "Winding Gulf—Destroyer 1-24"—"American Maritime Cases 1947-819."



DRAWING C

all about. The seaman, however, does not design, fabricate, or install the light. He operates and uses them in the course of navigating his ship. Certainly he should want an instrument which does what he expects it to do in the very best manner. Other factors in safe navigation, such as lifeboat design, ship stability, etc., are based on, and described, in the pertinent rules, in the terms and formulae of physics without disturbing the sailor. His primary requirement is to know how and when to use the tools of the profession, not to design them, manufacture them, or argue their "legality."

In the field of law one finds the application of practically every science known to man. Expert witnesses and laboratory reports ranging from chemistry to psychology seem to be ably handled by lawyers and judges. Photometry and colorimetry ought not be a stumbling block to the bar and bench!

Once the optical characteristics of the lights have been defined and standardized the spatial relationship between lights can be determined. Whether lights should be spaced three feet apart, or six feet apart, or some other distance apart, depends on the characteristics of the lights and on the distance at which the array is to be distinguishable as two or three separate lights. Relatively dim lights separated by an interval of three feet would be more easily discerned as separate lights (at the distance at which they could be seen) than lights of high intensity. The matter of spacing must be a compromise between the distance at which the lights are to be seen and the distance at which they are to be distinguishable as separate lights.

The spacing of the lights used for ranging, in the sense of indicating a vessel's course, also invite consideration. The several rules vary considerably in

this requirement. International requires the horizontal separation to exceed the vertical separation. Great Lakes require a minimum fifty-foot horizontal separation on vessels over 100 feet long and has no requirements for lesser vessels. Inland has no horizontal separation requirements. Panama Canal specified a horizontal spacing of at least three times the vertical spacing. Western Rivers omits both vertical and horizontal spacing requirements! In this case (range lights) it is again necessary to establish the photometric requirements for the lights before proceeding further. Range lights must be separated vertically a sufficient amount to insure discernment as separate lights at a given minimum distance. In addition, the horizontal spacing must be such that changes of course, within the arc thru which both side lights are visible ahead, will be positively indicated. Observation of high intensity range lights (lights of sufficient intensity to be seen for five miles) indicate that a spacing of fifteen feet vertically and twenty feet horizontally (in compliance with the International Rules) do not satisfy the performance requirement for course indicating lights. Objective observation of the Range Lights of a ship so fitted showed that, at a quarter of a mile ahead, they appeared as one light and did not separate at all within the arc where both sidelights were visible. The spacing of "range lights" is a subject for experiment to determine specifications which will result in these lights doing what the mariner expects them to do—and the courts suspect that they do!

Spatial relationships also involve the matter of specifying heights "above the hull." At any given candle power, color, and atmospheric condition, the distance at which a light can be seen is a function of its height above the observer's eye. It is therefore superfluous to prescribe heights above the hull, or deck, or some datum other than the water line, for the various lights. Prescribing a minimum range of visibility in itself prescribes the minimum height of the light. Prescribing a limiting height, such as, "not to exceed twenty feet above the hull," often results in rigging the light somewhat lower than a pilot house top and thereby cutting down the arc thru which the light is visible. Carrying the light a few feet higher might add many degrees to the arc of visibility but would, in some cases, such as the anchor light of a vessel 149 feet long operating under the U. S. Inland Rules, constitute a violation of the rules. Why the height of the masthead light, for example, should be related to the breadth of the vessel, and that between 20 and 40 feet is not clear. An important point occurs to me at this time and that is that attempts to determine the size, shape, and type of a vessel on the basis of the *running lights* (side, masthead, range and stern) she carries is a most fallacious reasoning process. These lights and the relative positions in which they appear are course indicators only. By their color, number, and relative positions they convey information that a meeting, crossing, or overtaking situation is developing. Overbearing action or close maneuvering taken on the premise that the other vessel is smaller because her lights are closer together or lower, or possibly not so bright as your mental conception of what they would be on a large vessel, can result in most embarrassing conditions when the "tramp steamer" you have been crowding suddenly becomes identifiable as a cruiser*!) If a light be located at such a height and in such a place that it can be seen at the specified distance and thru the specified arc then height requirements relative to the hull become unnecessary restrictions on the installer and in some cases even affect the structural design and location of masts, spars,

* Or the "small fishing vessel" is really a submarine! See "The Loss of H.M.S. *Truculent*," Shipbuilding and Shipping Record, Feb. 2, 1950, Pg. 153.

and fittings. Another recurrent source of controversy which ought to be removed is the "visible all around the horizon" requirement for a single light such as the anchor light, towing light, and range light. This requirement is usually satisfied to some degree less than specified. In this respect the Great Lakes Rules are more realistic than any others. If it is considered necessary to see a light from any point on the compass, then, ships and rigging and radar antennae being what they are, at least two lights are necessary to certainly (and legally) satisfy the imposed condition. The single range light, installed on the mainmast, directly behind the foremast and its rigging and fittings, is obscured in the direction where it should perform best, that is dead ahead. Installed forward of, and consequently lower than, the masthead light on the foremast, it performs its function as a range light very well but introduces the problem of haze illumination ahead of the pilot house. Two range lights on the after mast, Great Lakes style, is a far more satisfactory arrangement.

The foregoing is a somewhat brief treatment of the subject. Reference to the format of the rules, the language used, and suggestions such as employing a blue light for the stern light or different arrangements of anchor lights have not been developed as it is considered that these factors, tho important, do not lend themselves to the factual treatment guiding the writing of this article. The presentation of a "model set of regulations," which usually follows a critical statement, is also omitted, not because the author hasn't one in mind, but in deference to others interested in the field; mariners, ship builders and operators, lawyers, and engineers, all of whom must contribute special knowledge, skills, and experience to the formulation of anything that could have the attributes of a real model code.

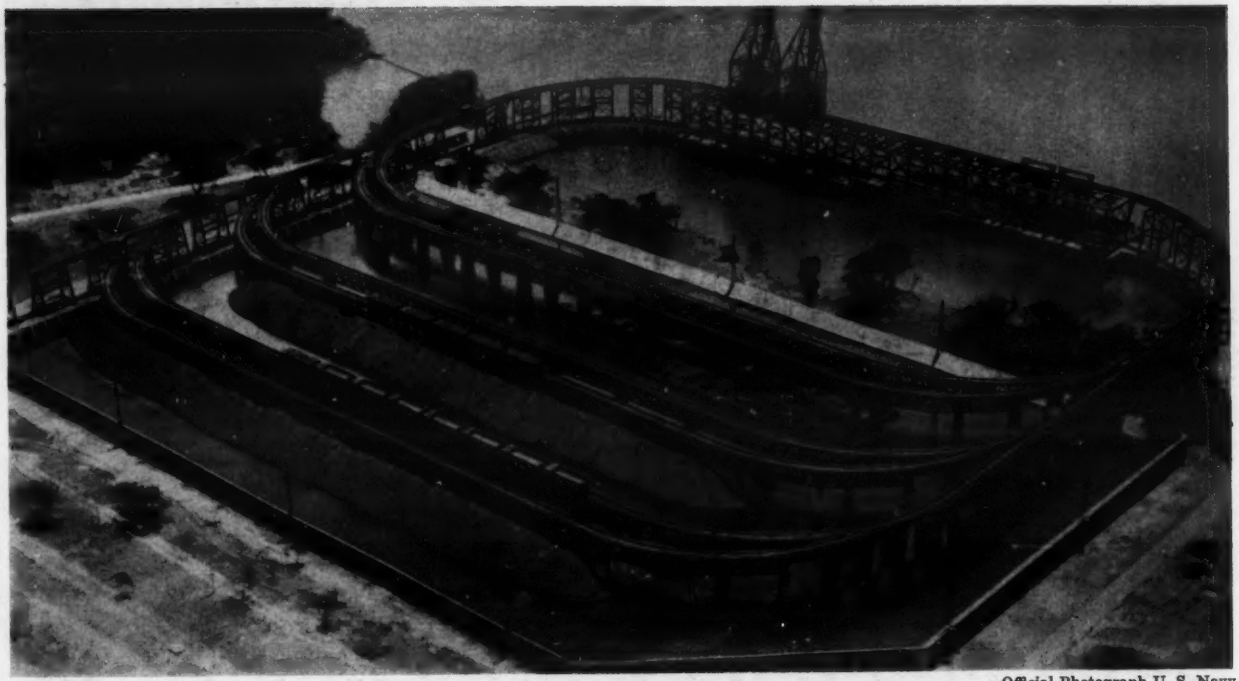
Summary

The regulatory laws pertaining to lights do not establish limits for variations from the basic requirements of the statutes. These variations are inherent in conventional navigation light design and are functions of light source, color and light transmitting qualities of glassware, dimensions of glassware and screens, positioning and color of screens, and other factors. Lacking the essence of the criteria for determining whether or not a certain light is in accordance with legal requirements, or is likely to perform as expected, all concerned are left to their own resources in arriving at decisions about lights.

The laws relating to lights might well be reviewed and set forth in one statute for all United States waters and another statute for the International waters, these two statutes to be administered by one agency under one set of regulations. By the application of modern engineering knowledge in a unified legal framework let the experience of the past be used for the benefit of the present.

Acknowledgment

The author wishes to give credit for critical review to C. O. Vermillion and R. J. Le Sage of the Design Division, Bureau of Ships.



Official Photograph U. S. Navy

COALING DOCK AT PEARL HARBOR NO LONGER IN EXISTENCE. AN OLD NECESSITY FOR LOGISTIC SUPPORT OF A NAVAL FLEET.

MARINE APPLICATIONS OF CATHODIC PROTECTION AND THE ELECTROCOATING PROCESS

HERMAN S. PREISER AND BENNETT L. SILVERSTEIN

THE AUTHORS

MR. HERMAN S. PREISER and MR. BENNETT L. SILVERSTEIN, both recent graduates of Webb Institute of Naval Architecture and Marine Engineering, have become intimately acquainted with the Cathodic Protection field while undertaking a corrosion thesis for the Bachelor of Science degree. MR. PREISER is presently connected with the Bureau of Ships as a Junior Naval Architect, MR. SILVERSTEIN is continuing his studies at Massachusetts Institute of Technology for a Master's degree in Naval Architecture. His thesis work under the direction of Dr. H. H. Uhlig, Associate Professor of Metallurgy in charge of the Corrosion Laboratory, concerns the investigation of the effects of velocity of the electrolyte on the cathodic protection and electrocoating of steel surfaces immersed in moving sea water. The data presented in this paper was obtained while preparing a thesis and is hereby published with the permission of Webb Institute.

INTRODUCTION

The battle between Man and Corrosion is one of long standing. For many years, rust has eaten away at metal structures and caused losses that are in the range of billions of dollars per year.

Iron and steel, the most widely used construction metals, have suffered greatly from the ravages of rust. To fully demonstrate the theories contained in this paper, it is necessary to comment about the mechanism of corrosion, as applied to iron immersed in an electrolyte.

Mechanism of Corrosion:

The present established Electrochemical Theory adequately explains most corrosion phenomena. Deviations from this are sometimes ascribed to various types of microbiological bacteria that have a marked effect on increasing corrosion. (1) (2) A few examples are the sulphate-reducing bacteria, the sulphur-oxidizing bacteria, and the bacteria that produce carbon dioxide or ammonia.

The initial reaction takes place at the anode and is:

1. $Fe(\text{metal}) + 2H\ (\text{ionic}) = Fe^{++}\ (\text{ionic}) + 2H\ (\text{atomic})$

In this equation, iron and the hydrogen are both grouped in the metal category where the iron is the more active of the two, thus displacing the hydrogen from the solution. The hydrogen plates out on the cathode and to some extent protects it from further action.

However, this equation is insufficient.

For further corrosion to continue, it is necessary to remove the atomic hydrogen which has occluded on the cathode. The removal of hydrogen may be effected in two ways—

It may bubble off as a gas—

2a. $2H\ (\text{atomic}) = H_2\ (\text{molecular})$

It may combine with oxygen to form water—

2b. $2H(\text{atomic}) + \frac{1}{2}O_2(\text{dissolved}) = H_2O\ (\text{liquid water})$

"The presence of the hydrogen film on the metal surface obstructs the reaction in two ways: 1) by insulating and separating iron from the solution and 2) by the increasing tendency of the hydrogen to reenter the solution and thus oppose the corrosion tendency."* This is the equivalent of lowering the potential difference between the metal and the electrolyte and is known as *polarization*. In order to continue the reaction to completion, the hydrogen must be removed. Oxygen is a powerful depolarizing agent for the removal of hydrogen. In cases where the supply of oxygen is limited, hydrogen can bubble off as a gas only when energy is supplied to overcome the *overvoltage* or resistance of the gas adhering on the metal surface.

The magnitude of this resistance depends principally on the surface condition of the metal and to a lesser extent. on temperature, pressure, nature and velocity of the corroding medium, and the size and numbers of the hydrogen bubbles formed. The amount of work necessary to oppose the surface tension of the solution for the formation and evolution of hydrogen bubbles, as influenced by the above factors, is a measure of overvoltage.

Another reaction, secondary but nevertheless important, is the oxidation of ferrous to ferric iron. The ferrous salts, for the most part, are much more soluble than the ferric. This relation is significant as it helps explain why iron corrosion products do not form effective films that prevent further corrosion. Figure Number 1 will explain the rusting of iron partially immersed in, as an example, a salt solution.(3)

It is important to realize that if the reactions 1. and 2. are to take place, the slowest reaction determines the rate of corrosion. It has been found, that in natural waters, other things being equal, the rate of corrosion is proportional to the oxygen content.(4) Thus, we can deduce that equation 1. plates out as much hydrogen as either 2a. or 2b. can effectively consume. Reactions 2a. and 2b. are usually very much slower than reaction 1. As an illustration, if we could materially increase the metal-ion concentration of the solution, thus causing a solution backpressure and a resultant slowing down of reaction 1., it would *not* change the rate of corrosion. These factors, however, are interdependent so that any change in conditions may alter the order of importance. Table Number 1 helps explain why possible error is incurred when corrosion rates between the different zones are compared.

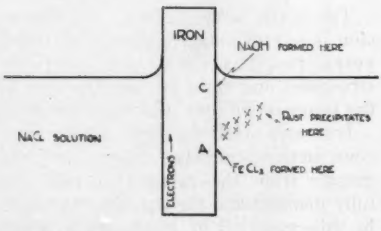


FIGURE NUMBER 1—Corrosion Cell. This is similar to the corrosion of a ship's hull in sea water.

(Reprinted by permission from "Corrosion Handbook", Edited by H. H. Uhlig, published by John Wiley & Sons, Inc. 1948.)

* From "Corrosion—Causes and Prevention", 2nd. Edition, by F. N. Speller, 1935. Courtesy of McGraw-Hill Book Co.

TABLE NUMBER 1

Effect of Various Factors on Corrosion

(Classified according to pH value and arranged in decreasing order of importance. Factors having asterisks (*) are of minor importance.)

Alkaline Zone—(pH > 10) (Corrosion-slow)	Neutral Zone—(10 > pH > 4.3) (Corrosion-medium)	Acid Zone—(pH < 4.3) (Corrosion-fast)
Protective Coatings	Oxygen Concentration	Hydrogen-ion Concentration
Oxygen Concentration	Protective Coatings	Hydrogen Overvoltage
Composition of Metals	Hydrogen-ion Concentration	Composition of Metal
Hydrogen-ion Concentrations*	Composition of Metal*	Oxygen Concentration
Hydrogen Overvoltage*	Hydrogen Overvoltage	Metal-ion Concentration*
Metal-ion Concentration*	Metal-ion Concentration*	Protective Coatings

(From "Corrosion—Causes and Prevention", 2nd. Edition, by F. N. Speller, 1935. Courtesy of McGraw-Hill Book Company.)

The variation of conditions that exist in different environments also tends to complicate the corrosion situation. In the past few years, science has marshaled its forces to combat this "disease of metal," and many methods have been devised to diminish and prevent rusting.

Cathodic Protection:

Various types of paints and coatings have been developed by government agencies (National Military Establishment, etc.) and private industry that have proven satisfactory under certain environments. Rust inhibitors and surface passivators have been employed successfully in some instances. Another method, not new, but just recently coming into its own, is *cathodic protection.*

This system has been embraced by many oil companies to safeguard their pipelines that are embedded in corrosive atmospheres of various earths. Others, as the shipbuilders, boiler manufacturers, etc., are sponsoring intensive research to adapt cathodic protection to meet their own particular requirements.

Cathodic protection may be defined as "The use of an impressed current to prevent or reduce the rate of corrosion of a metal in an electrolyte by making the metal the cathode for the impressed current."*(5)

This may be accomplished in two ways:

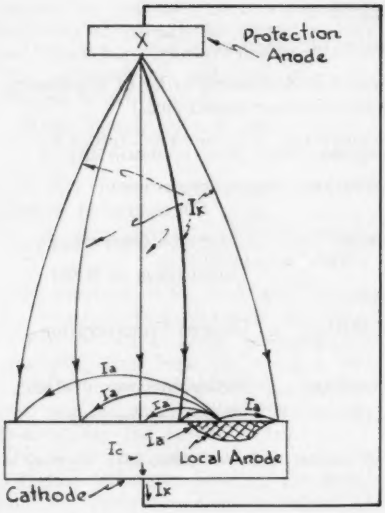
A. A sacrificial anode (such as zinc or magnesium) may be employed. The current generated here is the result of a galvanic couple. The zinc, when connected with iron in an electrolyte, is a more active metal, thus it protects the iron at the expense of the zinc.

B. The use of impressed current from a soluble or inert anode.
   1. Generated direct current.
   2. Rectified alternating current.

Method A. has some objections:

Zinc, unless of extremely high purity, may not generate enough current after a short time in spite of its high anodic corrosion efficiency (over 90%), as corrosion products form an insoluble film on the zinc which impedes the flow of current. (6) (7)

* Reprinted by permission from "Corrosion Handbook", edited by H. H. Uhlig, published by John Wiley & Sons, Inc., 1948.



I_x = Externally applied current
I_a = Current from local anode
I_c = Total current to cathode
E_{ac} = Potential drop between local anode & cathode
E_a = Unpolarized, or open circuit, potential of local anode
E_c = Unpolarized, or open circuit, potential of local cathode
ϕ_a = Polarizing function of local anode
ϕ_c = Polarizing function of local cathode
A_a = Area of local anode
A_c = Area of local cathode

Using Kirchhoff's Laws: $\left[E_a - \phi_a \frac{I_a}{A_a}\right] - \left[E_c + \phi_c \frac{I_c}{A_c}\right] = E_{ac}$

$$I_c = I_a + I_x$$

If the resistance of the electrolyte is small:

$$E_a - \phi_a \frac{I_a}{A_a} = E_c + \phi_c \frac{I_c}{A_c}$$

For protection, $I_a = O$ or reversed in direction. Minimum current necessary is obtained when $I_a = O$.

$$\therefore E_a = E_c + \phi_c \frac{I_c}{A_c}$$

FIGURE NUMBER 2—Cathodic Protection.
(From Brown & Mears, "Cathodic Protection", 1942, Transactions Electrochemical Society)

Magnesium, though higher in the electromotive series than zinc, and in spite of the non-adhesion of its soluble corrosion products, has a much lower anodic corrosion efficiency (about 45-60%) due to local action.(8) *Magnesium anodes have performed successfully in many applications of cathodic protection and their commercial utilization in pipeline and piling protection is significant.*

The general mechanism of cathodic protection can be explained by Figure Number 2.(16) The problem of the ship owner and operator is such, that to maintain I_x so that $I_a = O$ is almost impossible. At different points on the hull, wide variations of conditions can be expected due to heterogeneity of the metal surface, unequal distribution of stresses, variance of oxygen concentration, breaks in the paint film, galvanic

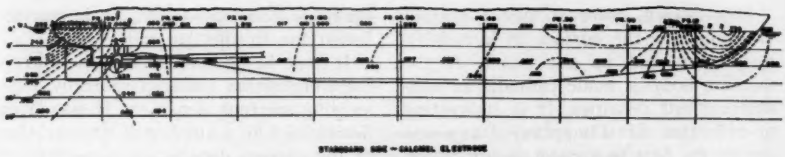


FIGURE NUMBER 3—Electric field on U.S.S. Kingfish.
(Courtesy of BuSHips, Navy Department, Washington, D. C.)

action at the stern due to the bronze propeller—steel stern couple, and non-uniformity of local velocities of electrolyte. In addition, protective hydrogen bubbles are washed away by the velocity of the rapidly moving salt water.(9) Therefore, E_a and E_c will vary such, that a determination of I_x is very difficult. (See Figures Numbers 3 and 4.)

However, if we go one step further, and increase I_x substantially over its minimum value, an entirely new situation occurs. If the hull is immersed in sea water, a white deposit of calcium and magnesium salts (and some trace of other elements and compounds) is plated out on the metal.

The properties of the coatings thus formed will vary greatly with the amount of impressed current. Some of these coatings deposited under carefully controlled conditions have been suggested as protective coatings in their own right, and as such are the subject of U. S. patents.(10) (11) These coatings on metallic surfaces immersed in sea water are sometimes known as "high current density polarization coatings," "marine electrocoatings," "calcareous coatings" and "Cox coatings."

The remainder of the article will deal with the development of this patent and its practical adaptation to the marine industry and Navy.

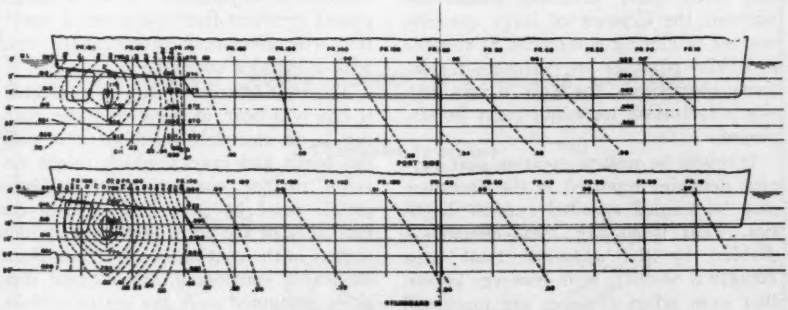


FIGURE NUMBER 4—Electric fields on U.S.S. Farenholt (DD 491)
(Courtesy BuSHips, Navy Department, Washington, D. C.)

HISTORY AND DEVELOPMENT OF THE MARINE ELECTROCOATING

Nature of Electrocoatings:

The characteristics of electrocoatings formed over a wide range of current densities has been the emphasis of experimental work carried on by Col. G. C. Cox and his associates since 1935.(19) Many theories have been advanced as to the exact mechanism of the forming of these electrocoatings on metals, although the validity of the chemical equations has not definitely been established. The chemistry and analysis of these coatings can be found in the technical literature.(10) (11) (12) (13) (15) (17)

It is known, however, that a coating *is* formed on the surface of a metallic body immersed in sea water, if the metallic body is made cathodic at suitable current densities. It is interesting to note that Sir Humphrey Davy was one of the first to record the formation of such a coating.(12)

In many cathodic applications where a salt water electrolyte is utilized, a calcareous coating is formed whether or not it is desired. In almost any situation, where current densities are much in excess of the amount needed to just maintain a protective polarization potential at the cathode, a coating will be deposited. It is only over specified ranges of current density (which vary with temperature, velocity and conductivity of the electrolyte) that the coatings have the desirable protective properties of good adherence and low porosity. In some cases, low current density polarization (cathodic protection) is all that is necessary, i.e., protection of fleet reserve vessels in sheltered waters. This, and many other instances would not warrant the expense of large capacity current producing equipment. If suitable protective coatings are desirable in relatively short times, the high current density polarization technique must be employed.

It might be well to mention that current densities reported in the literature may be termed *nominal* current densities. That is to say, total current is divided by the *apparent* total area (length x width). It is however known that even when surfaces are machined accurately, a microscopical examination reveals astronomical numbers of high peak and deep valleys. Newly developed means of measurement are availble which indicate that a *true* surface exists which is at least 10 times the magnitude of the *apparent* area. Therefore, current density determination is difficult. Specimen areas have no precise meaning unless the *true* surfaces are comparable. Unfortunately, in the past this important source of error has never been seriously considered.(20) It is not allowed for in this paper.

It must be understood that the chemical composition changes radically with varying current densities. It has been determined by a number of sources, that as the current density increases from 0 milliamperes per square foot to, say 400 milliamperes per square foot, the ratio of calcium to magnesium decreases.(8)(15) This can best be shown by Figures 5 and 6. It is obvious from these drawings that the practice of calling this coating "calcareous" is erroneous—for, although the ratio of calcium to magnesium is high at low current densities, at 400 milliamperes per square foot, the ratio of calcium to magnesium is 0.228.

If, for example, a few milliamperes per square foot are found to be able to maintain a coating over a given area, this would mean that the total current consumed divided by the entire area of the surface protected is the average current density required. This gives an inaccurate impression if it is interpreted to mean that low current densities will adequately protect bare steel with a suitable coating.

This mis-statement can be corrected, if one will bear in mind that the coating is an electrical insulator, and only the pores and cracks which might develop in the coating—exposing bare metal—must be protected. (Since the total area of the pores and cracks which appear in the coating is a fraction of the total area considered, low current densities computed over the entire surface, in reality become sufficient to deposit a substantial coating on these minute exposed surfaces.) The "self-healing" (11) ability of this coating is claimed to be one of its inherent properties that can be effectively employed to protect almost any shaped surface, and to seal any breakdown in the coating which may occur from time to time.(18)

As far as can be determined at present, the magnesium compounds form an amorphous matrix which functions

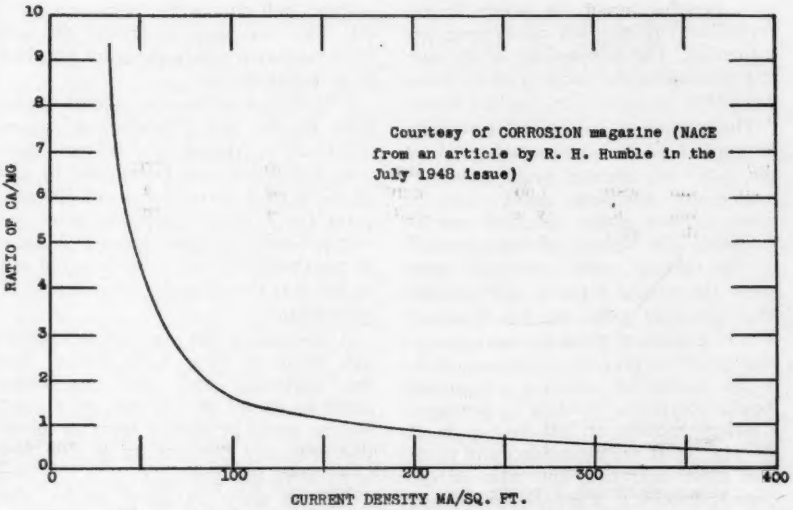

RATIO OF CA/MG
CURRENT DENSITY MA/SQ. FT.
Courtesy of CORROSION magazine (NACE
from an article by R. H. Humble in the
July 1948 issue)

FIGURE NUMBER 5—Composition of calcareous coatings formed in sea water; current density versus Ca/Mg ratio.

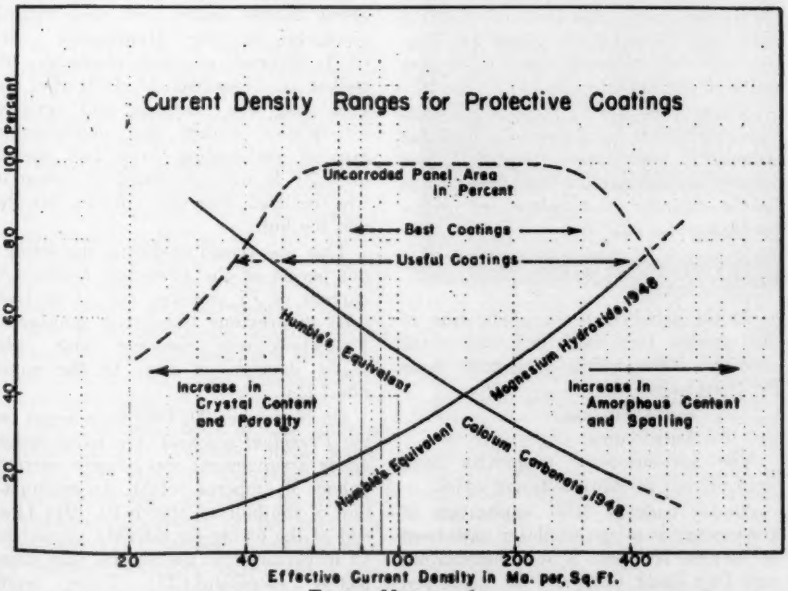

Current Density Ranges for Protective Coatings
Uncorroded Panel Area in Percent
Best Coatings
Useful Coatings
Humble's Equivalent
Magnesium Hydroxide, 1948
Increase in Crystal Content and Porosity
Increase in Amorphous Content and Spalling
Humble's Equivalent Calcium Carbonate, 1948
Effective Current Density in Ma. per Sq.Ft.

FIGURE NUMBER 6.
(Reprinted from Corrosion, Vol. 6, May, 1950, p. 165.)

as a bonding agent, in which microcrystalline calcium-rich constituents are suspended. The composition of the matrix determines the ductility of the coating.(10)

The analogy of concrete mixtures may be applied to the electrocoating where the ratio of calcium (aggregate) to magnesium (bonding agent) can be made to vary under specified current densities. The highest inherent strength of the coating would naturally occur when the critical ratio of calcium salts to magnesium salts can be deposited. The dispersion of these microscopic calcium particles prevents shrinkage cracks in the magnesium matrix; a relatively tough, non-porous coating is produced. Coatings formed at 100 ma/sq. ft. to 200 ma./sq. ft. are most dense and therefore most desirable. The ratio of calcium hydroxide to magnesium carbonate is approximately one in this range. (See Figure Number 6.) It has been established that a total current of 6-10 ampere hours/sq. ft. produces optimum results.(19) It is also believed that the CO_2 dissolved in the electrolyte materially aids in hardening the coating after its formation.(18)

Many properties of these electrocoatings have been investigated in field and laboratory experiments. Certain phases of the coating have proven their worth to the engineer while others are undergoing careful analyses.

Anti-Corrosive Properties of Electrocoatings:

In the problem of the application of this process to a ship's hull, two of the coating's outstanding properties must be considered:

A. Anti-corrosion.
B. Anti-fouling.

The anti-corrosive properties have been proven in many different cases.

As far back as 1940, application of the coating as a rust inhibitor have been in service. Newport News Shipbuilding and Dry Dock Company has employed this process on the underwater areas of a ship's hull during the fitting-out period. This was done to protect the hull from corrosion where the paint film had been damaged.(13)

The electrocoating was applied in two tests to the tug *"Huntington"* from March 20 to August 12, 1940 with success. Protection was maintained by applying a total current of about 300 amperes for 12 hours each day, after the original coat had been formed. A lapse of treatment of over four days did not in any way decrease the effectiveness of preservation.(21)

A secondary, but nonetheless important, result of these tests showed that the electrodes and other equipment could be placed at the dock, as a good coating could be applied from an anode that was any distance up to 200 feet away from the hull.(22)

Due to these excellent results, the process was tried out on a few ships of the President line.

The *President Monroe*, a C-3 type of ship having an underwater hull area of about 26,000 square feet, was treated similarly to the *Huntington*. Mr. O. J. Streever, engineer in-charge, reported, on September 11, 1940, that the protection was complete and entirely satisfactory, except that considerable area of anti-fouling paint had peeled off.(22) It was accounted for when it was realized that the current density was too high.

This was remedied during the fitting-out period of the *President Hayes*. A current of 75 amperes (or ¼ of that used in previous tests) was employed. Protection was complete with only slight damage, if any, to the paint film.(22)

On November 29, 1940 tests began on the *President Garfield*, involving better anode arrangement and a lower current (about 50 amperes, total). An examination of the hull on March 10, 1941 (the end of the fitting-out period) proved to all inspectors that the process was completely successful.(23) There were slight amounts of red oxide visible, but

upon further examination, the coating was found underneath.

A further development of the process was carried out on the *President Adams* from February 12 to May 14, 1941. Anodes were arranged to give a uniform deposit and the current adjusted to give as thin a coating as possible and still be protective. The inspectors were unanimous in their opinion that the hull was in excellent condition.(22)

From a commercial viewpoint, the coating left on the hull, at the end of the fitting-out period, was undesirable as it would have to be removed so as to permit painting according to standard procedure. The *President Van Buren* was treated as the *President Adams*, except that the process was discontinued about two weeks prior to dry docking. The current was shut off on August 9 and the hull inspected on August 21, 1941. It was found that there was no coating left on the underwater surface. No deep pitting occurred but on all bare areas there was a thin surface film of rust.(22)

As a final test of this series, it was decided to duplicate these conditions on the *President Polk*. The results were the same as those obtained on the *President Van Buren*.

Since these preliminary trials, Newport News has employed this system on the USS *Hornet*, the USS *Birmingham*, the USS *Mobile*, the USS *Essex*, the USS *Yorktown*, the USS *Intrepid*, the USS *Biloxi*, the USS *Houston*, and many others with satisfactory results. (24) It is not known whether Newport News has adopted these encouraging indications to their standard shipyard procedure.

The corrosion tests of the International Nickel Company have amply shown the value of the coating over and above that afforded by electrochemical suppression of the corrosion reactions.(17) In one particular case, a specimen was Cox-coated with a protective current applied for only 1/3 of the total time. Where a similar specimen was subjected to a continuous current flow, the protection was not as effective as that on the first specimen.

Anti-fouling Properties of Electrocoatings:

The value of the Cox coating as an anti-fouling agent has been under fire for many years. As this phase is the controlling one, extensive and detailed research was necessary. The problem of the fouling of a ship's hull in sea water is one that cannot be neglected. It presents a problem source equal to, if not greater than, that of corrosion.

Full discussions of the mechanics of fouling, typical organisms and various controls applied, may be found in many technical libraries.(25)(26)(27) However, certain facts arrived at from different data are pertinent.

1. Typical organisms, in the order of their usual frequency and

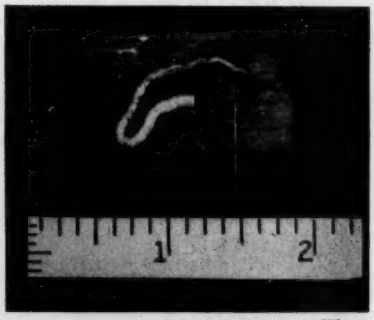


FIGURE NUMBER 7—*Annelids or Worm Tubes.* These organisms can be readily recognized by the hard tubular shell which adheres firmly to the surface of the hull. This hard tube actually houses the living worm. These annelids range in size from a fraction of an inch to several inches in length, and may form a large proportion of the fouling, especially on ships which have been stationed in the Hawaiian Islands or the southern Pacific. One of the common attachment forms is called *Hydroides*. This should not be confused with the Hydroids, an entirely different type of organism.

(Courtesy of Daniel P. Graham
Bureau of Ships
Washington, D. C.)

Acorn Barnacle Stalked Barnacle

FIGURE NUMBER 8—*Barnacles.* In many waters the barnacle is the predominant fouling form. Two general types of barnacles are found. The *acorn barnacle* consists of a conical hard shell which is made up of several distinct plates. The top of this cone is covered by two distinct plates which are separate from those which make up the shelf itself. These organisms may vary in size from a fraction of an inch to several inches in diameter at the base of the cone. These barnacles may drop or be knocked off of the hull. A basal, limy plate is left behind when this occurs. In the figure to the left a basal plate is shown on the front of the large group of barnacles shown. The other type of barnacle is the *stalked* or *goose neck barnacle.* Whereas the acorn barnacle is attached to the hull by the calcareous plates which form the cone shaped shell, the stalked barnacles have a muscular stalk which holds the body away from the hull. The body proper of both types is always protected by limy plates.

(Courtesy of Daniel P. Graham
Bureau of Ships
Washington, D. C.)

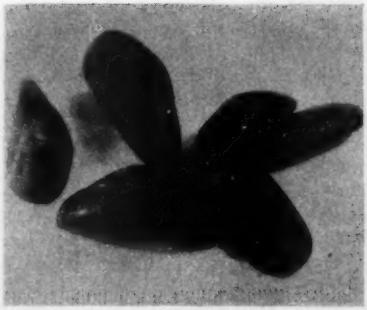
abundance, are barnacles, hydroids, worm tubes, algae, tunicates, Bryozoa, mollusks and Protozoa.(26) (See Figures Number 7-13.)

2. Fouling occurs almost entirely while vessels are in port.(26)

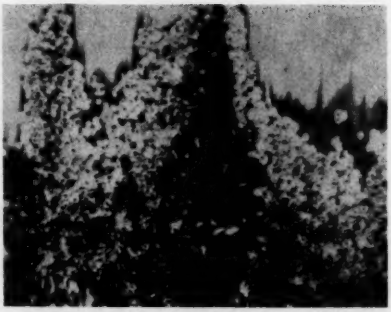
If velocities can be maintained over two knots, fouling is reduced to a minimum.(25)(26) However, if the organisms do attach, many will grow and flourish at higher speeds.

Some methods of control that bear mentioning are:

a. Control by Anti-fouling Paints (28)—this has been found satisfactory, but only for a limited time (about two to four years). It is interesting to note that tests were conducted at the Norfolk Navy Yard in 1943 employing the Cox-coating as a primer for various Navy Standard Anti-fouling paints. In this capacity, the Cox-coating has no advantages over ordinary primers(29) and the disadvantage of the necessity of a maintenance current to preserve the coating. Experiments performed at the Engineering Experiment Station, Annapolis, Maryland, in 1943, show that cathodic voltages above four tenths volt are destructive to certain ship-bottom paints and paint systems.(30)
b. Control by Chlorination.(25)
c. Control by Heat.(26)
d. Control by Acid—low pH will, in general, anesthetize various organisms, i.e., barnacles.(25) Higher pH actually encourage the flourishing of some organisms, i.e., algae.(31)



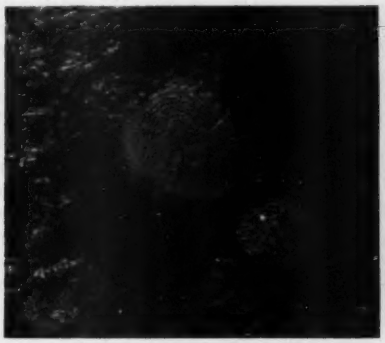
Molluscs, (mussels)



Molluscs. Mussels attached to pilings, (surrounded by barnacles)

FIGURE NUMBER 9—*Molluscs, shellfish or bivalves.* This group includes the familiar edible clams, oysters and mussels. All of the forms important in fouling are characterized by having paired or "two valved" shells. They are generally attached to the hull at the region of the hinge of this double shell. Very many shapes are found, but all are characterized by this paired hinged shell, a structure not found in any other group of fouling organism. The molluscs may grow to a large size, and since they may become attached to other molluscs which in turn are attached to the hull, they frequently build up a large bulky mass of fouling.

**(Courtesy of Daniel P. Graham
Bureau of Ships
Washington, D. C.)**



Bryozoa, (coral patches)

Bryozoa, (soft bodied forms)

FIGURE NUMBER 10—*Bryozoa* (coral patches). The Bryozoa include some soft bodied, and some hard bodied forms. All Bryozoa are colonial animals, the colony being made up of hundreds of thousands of minute individual organisms. The colony may vary in appearance from a moss-like mat of material to a branching colony suspended by a single strand, to a thin encrusting growth (so called coral patch) which spreads over a large area. When an adult barnacle falls off of the hull it leaves behind a circular patch or base plate. This may resemble a coral patch. The base plate of the barnacle is marked by rings, whereas the coral patch is distinctly granular in appearance. The flat encrusting growth is frequently hard and calcareous in nature, whereas the branching type is generally soft.

**(Courtesy of Daniel P. Graham
Bureau of Ships
Washington, D. C.)**

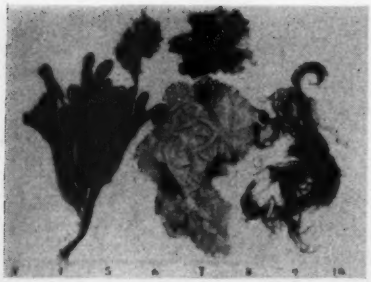


FIGURE NUMBER 11—Algae. Top row—Left, green; right, red. Bottom row—left to right, brown, green and green. Soft bodied forms.

Algae (green moss). Just below the water-line a green zone fouling is frequently found. This fouling is made up of the algae, the true marine plants, and is commonly called moss. Since these plants require light in order to grow they are seldom found on the deeper portions of the hull between the bilge keels. The commonest types of algae are grass green in color, but blue-green, brown and red algae may also be found. The green, blue-green and red algae which are characteristic fouling organisms consist of mats of long slender threads or filaments. The brown algae, on the other hand, are the typical rockweeds of the coast, and are made up of large flat fronds, which are similar to the leaves of land plants. These fronds are in turn attached to the hull by a relatively narrow stalk. These brown algae are tough and leathery in nature, and the surface is always very slimy.

(Courtesy of Daniel P. Graham
Bureau of Ships
Washington, D. C.)

e. Control by Electrical Methods—phases of this possibility have been tested and reports were made.(31)(32)(33)

If it were possible to prevent fouling by electrical means, it would work naturally hand in hand with the equipment employed in applying the electrocoatings. Many suggestions were brought forth; some were debunked, while others showed promise.

It was observed that neither the existence of an electric charge on the surface nor the fact that current was flowing, hindered the attachment of fouling organisms. Instead, the organisms adhered just as readily to the coating as to the bare metal.(17)(51) In addition, it was found that pulsating or intermittent current did not prevent the organisms from attaching, and that it was not economically feasible to electrocute them. 1,000,000 milliamperes per square foot was insufficient to kill small barnacles.(32)

These results, and others, narrowed the possibilities down to the original premise. This was that, at suitable current densities, the coating formed could flake off easily, taking the fouling matter with it. See Figures Number 14, 15 and 16.

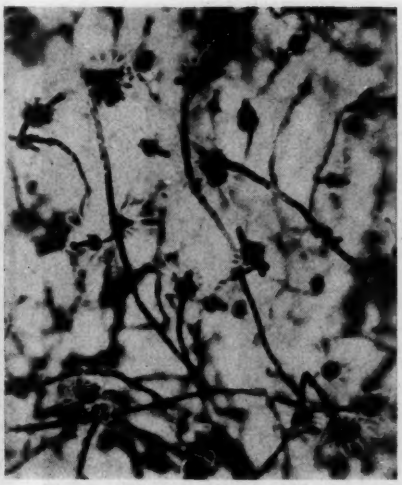
There have been a few theories forwarded to explain why this exfoliation occurs; it is quite possible these work in conjunction.

A. As an electrocoating is built up on a metal surface, succeeding layers form on the bare metal and displace the film already present. At high current densities, the layers have a low ratio of calcium to magnesium. (See Figure Number 6.) The magnesium compounds are soft and do not adhere well to the metal beneath; mechanical failure will occur due to inter-granular breakage, loosening the bond between the coatings and the metal.(23) The result is similar to that of coating steel with animal glue and allowing it to dry.(18)

B. At high current densities, cracks form in the coating, permitting the electrolyte to reach the metal beneath. Hydrogen bubbles form and tend to blast off the coating.(18)

C. At low current densities, the deposit is mostly calcium crystals (much like sand particles). If it were practicable to apply a coating to a ship's hull at about 2 or 3 milliamperes per

Hydroids, attached to panel, normal size



Hydroids, enlarged view

FIGURE NUMBER 12—*Hydroids* (grass) The hydroids are small animal forms, commonly called grass. These forms are colonial in nature, so that each distinct group is made up of many individual organisms. All of these are composed of a stalk which may be branched. At the end of each branch a somewhat larger expansion is found. This expansion of the tip is frequently pink in color and readily distinguished between the branching Byrozoans and the hydroids. These organisms when attached to the hull form a pale cream or tan mat which may be very extensive and thick.

**(Courtesy of Daniel P. Graham
Bureau of Ships
Washington, D. C.)**

square foot (the time element would probably be great) and then wash this coat away by moving the ship at certain velocities, a bare surface could be obtained, as the fouling matter would wash off with this sand-like coating.(18) It is important to note that organisms attached themselves to the *outer layer* of the electrocoating and did not eat through to the bare metal.(32)

Past Experiments:

The problem then became that of finding an optimum current density that would effectively defoul and yet be economically feasible. Experiments were undertaken on the possibility of cleaning ships' hulls by this method, employing various current densities and anode

FIGURE NUMBER 13 — *Turnicates* (sea squirts). The turnicates are soft bodied, spongy forms, characterized by their ability to eject a stream of sea water for some little distance, hence their common name of sea squirts. In this figure a photograph showing a region heavily fouled by turnicates is shown. This figure gives a good impression of the soft, spongy nature of this organism.

**(Courtesy of Daniel P. Graham
Bureau of Ships
Washington, D. C.)**

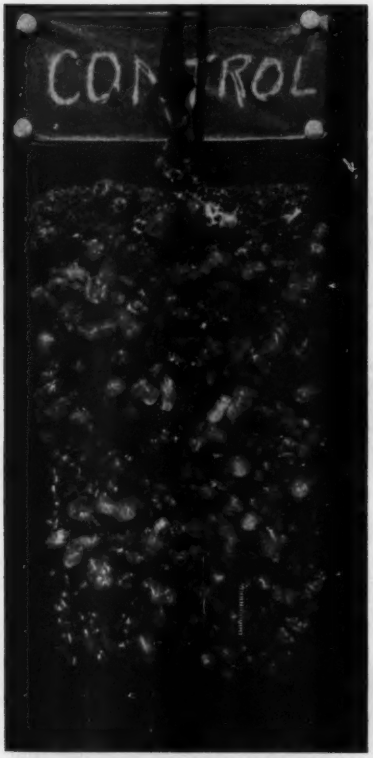


FIGURE NUMBER 14—Photograph Numbers 14-16 show different degrees of exfoliation by the use of the electrocoating process after seven months test in English waters.
Control Panel—no treatment, normal growth 7 months.
(Courtesy of Col. George C. Cox.)

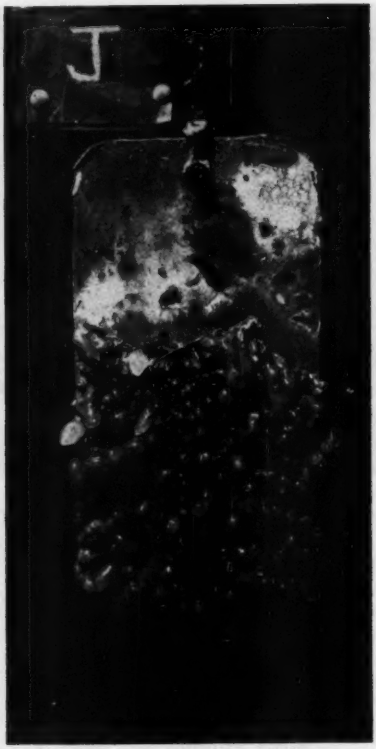


FIGURE NUMBER 15—*Panel J*—partial descaling after 7 months growth.
(Courtesy of Col. George C. Cox.)

arrangements. An interesting offshoot of these investigations was the disclosure that tank-ship compartments can readily be derusted by this electrolytic process. (See Figure Number 17.) The economy of this over sandblasting has been shown by results of experiments at the Newport News shipyard sponsored by the U. S. Army Transportation Corps and by the Navy Department.

Early in 1941, Newport News began an ambitious experiment to exfoliate the fouling matter from the hull of the SS *Winona County*.(33) This vessel was very heavily fouled due to the fact that it had not been dry docked in about four years.

Power was obtained from two 1250 ampere welding units at low D.C. voltage. Seven tests were made at varying current densities and of different time duration. An example of the results obtained, was that for a current of 1300 amperes for six hours, an area of 15 square feet was completely cleaned down to the bare metal. High pressure hosing (300 psi.) increased the area to about 70 square feet.

FIGURE NUMBER 16—Panel O—complete descaling after 7 months growth.
(Courtesy of Col. George C. Cox.)

"The SS *Winona County* tests indicated that very rapid descaling could be successfully carried out at comparatively high current densities. However, the costs of using this *grid electrode* type of procedure were excessive and this phase of the investigation at Newport News Shipyard was therefore indefinitely postponed." (Courtesy of Col. G. C. Cox)

Though the results were not favorable by themselves, they point the way toward future developments involving better anode design. Conditions met in these tests were extreme and would not be encountered in actual practice. If a hull was electrocoated and maintained from the outset, at the time of exfoliation, there should be no paint film, very little rust, and only the first stages of fouling present. Hence, it is believed that exfoliation could be accomplished with much lower current densities for shorter periods of time.

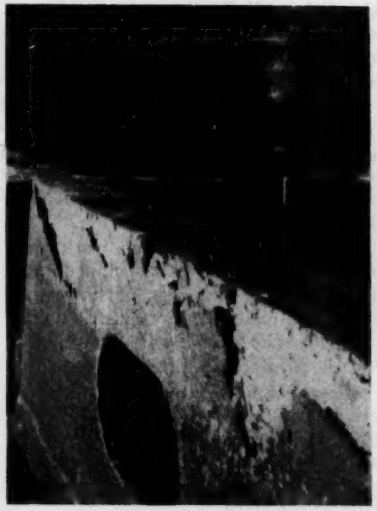


FIGURE NUMBER 17 — This photograph shows the descaling of heavy rust on a girder in the bottom of an aviation gasoline-carrying tanker.
Treating time was 48 hours.
(Courtesy of Col. George C. Cox.)

Since these simple tests, the Army Transportation Corps has done a great deal of research and development at the Newport News Shipbuilding and Drydock Company. New anode designs were employed and improvements and variations of the process were experimented with on the "FS-212" and other Army ships.

Many different materials have been used as anodes for the impressed current method. Carbon, used in early experiments, is cheap and readily available. However, it is brittle and must be handled with care. In addition, in closed tanks, undesirable chlorine and hydrogen gases are formed.

Steel anodes have been employed, notably by the British(34)(35(36).

Although negligible amounts of chlorine and hydrogen gases are evolved, the anode will dissolve too quickly for any kind of permanent installation.

Platinum wire is considered to offer a definite possibility(37) because it can be handled, and its weight loss is negligible as far as can be practically determined.(58) However, chlorine and hydrogen gases are produced.

At Newport News much work was done and valuable data compiled pertaining to hull cleaning. This was accomplished under "Operations 3 and 5" (Sponsored by U. S. Army Transportation Corps).(38)(39)

"Operation 3" consisted of testing different arrangements and methods of handling electrodes. Results were satisfactory and anodes were employed that successfully cleaned difficult areas, as those at the stern.

"Operation 5" attempted to remove the initial electrocoating (plus all attached marine growth which was present on the hull) by means of cathodic treatment at high current densities. Results, though encouraging, were only partially successful. It was suggested, however, that if immediately after the high current densities had been applied, the ship had been propelled at high velocities, much more of the growths would have been removed.

Other "Operations" were conducted that bear mentioning:

"Operation 4" covered the application of an electrocoating to the underwater portion of the "FS-212" and the current densities necessary to maintain the protectiveness of the coating.(40) It was found that, in still water, a current density of 200 milliamperes per square foot applied for 150 hours to an area of 700 square feet gave a dense, thick, protective coat. After this formation, magnesium anodes were so placed as to maintain the coating for 26 days. (Estimates indicated a current density of about 3 milliamperes per square foot.)

"Operation 2" was performed to determine if it was economically feasible to electro-clean a non-submerged surface, such as a ship's deck.(39)(40) Results were conclusive; current density ranges of 100 to 500 amperes per square foot were not sufficient whether the deck was made cathodic or anodic. Anodic treatment was twice as successful as cathodic treatment in the removal of paint and scale, but arcing occurred which was very destructive. [British experiments with deck cleaning was more promising using current densities in the 100 ma./sq. ft. range.(36)]

"Operation 1" was by far the most successful phase of all. This was to descale, clean and apply a protective coating to heavily corroded compartments of a tank ship.(39)(41)(42)(43)

To descale and derust, various current densities were applied for different time durations. Results showed that with 200 milliamperes per square foot of cathode surface with an electrolyte of sea water having a $_{p}H$ of 8, a temperature of 60° F. and a specific gravity of 1,017, complete descaling and coating occurred in 48 hours.(39)

ELECTROLYTIC DERUSTING AND DESCALING

The Navy Department has this phase under consideration. Many investigations connected with the electrolytic derusting of metals uncovered the necessary data which led to further full scale experiments.(58) One explanation of the ability of electrolytic means to derust and the chemical reactions involved is given in reference(44). In February, 1948, descaling operations of two wing tanks of the USS *Cimarron* (AO22) were completed.(45) A current density of 235 milliamperes per square foot for a period of 46 hours descaled completely, except for a few flecks of white deposit. Preliminary estimates of cost indicate

its economic superiority over other methods employed in present practice.

Since then, the process has been improved to the point where it may take precedence over mechanical and/or chemical methods of derusting and descaling a tank. According to latest reports(37) good descaling—with no white deposits—has been accomplished. This was done using platinum wire anodes suspended in the tank by nylon threads, immersed in an electrolyte of fresh water in which one percent NaCl, by weight, had been added. A current density of 100 milliamperes per square foot for 96 hours was used.(58)

A further test along these lines by the Navy used fresh water with less than 1% H_2SO_4, by weight, added.(37) A current density of 200 milliamperes per square foot through platinum wire anodes, suspended by nylon thread, was applied for 60 hours; satisfactory descaling and derusting was accomplished. After subsequent scraping, the sides of the tank were ready for painting. It is thought that by using this method of cleaning in conjunction with newly developed vinyl vinylidene chloride coatings, a very anti-corrosive atmosphere can be obtained on tanks of gasoline carrying vessels.

In addition, the British have experimented with this process(34)(35) and have come up with formulae for anode placement (36).

APPLICATIONS OF ELECTROCOATINGS

Another application of the electrocoating process, is the possibility of coating a compartment of a tanker that is to carry high-test gasoline. Aside from the anti-corrosion and cleaning aspects of the process, the coating, to be of practical use, should not dissolve in the gasoline or have any adverse effects upon it.(46)

This process has been applied to a ⅛ scale model of a compartment of the *Esso Richmond;* a protective coating was formed.(22) This coating deposited not only on the clean, sandblasted surface, but also under any rust spots. These indications seemed to point toward a brilliant future.

However, reports of the use of the electrocoating on two gasoline-carrying tank compartments of the USS *Salamonie* were not favorable.(47) The authors believe that this report was not conclusive as the anode design was poor —in fact, during the test, three of the five anodes fell into the tank because the steel link supporting them had corroded. Current densities varied over the surface due to this particular anode arrangement, thus depositing thick, soft coatings on some plates and hard, thin coatings on others.

The successful application of cathodic protection to inhibit corrosion of partially submerged steel structures in sea water has recently been adopted commercially.

H. A. Humble has thoroughly investigated the nature and severity of corrosion attack on steel specimens under actual conditions of alternate immersion and exposure to marine atmospheres at Kure Beach Testing Station. (48) Data compiled at the experimental site indicate that corrosion proceeds most rapidly in the spray and splash zone. See Figure Number 18.

Protective paint coatings have been developed which perform adequately on all surfaces above the tidal zone. However, no satisfactory paint system has been devised for the protection of submerged surfaces for an extended period of time. Although the corrosion rate is less marked in the immersed zone when compared to the splash zone, it is nevertheless serious in shortening the design life of the structure. Marine growths accelerate failure of under-

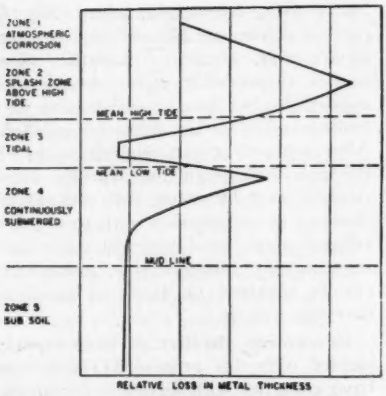


FIGURE NUMBER 18—Corrosion profile of steel piling 5 years exposure in sea water at Kure Beach, N. C. (International Nickel Co.).

(Reprinted from Corrosion, Vol. 5, Sept. 1949, p. 292.)

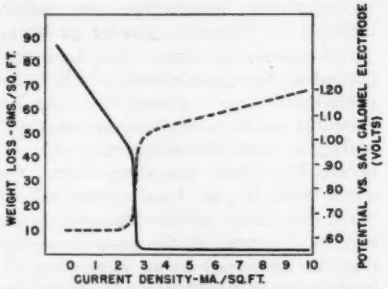


FIGURE NUMBER 19—Weight loss and potential of coated plates versus applied current density after one-year exposure in Sea Water. (The Dow Chemical Co.)

(Reprinted from Corrosion, Vol. 6, July 1950, p. 219.)

water paint systems and the life of these coatings rarely exceeds three years. It has been confirmed by experiment (8)(48) that corrosion of submerged surfaces can be practically eliminated by cathodic protection and that such protection reduces the rate of attack on steel piling in the tidal zone.

A particular installation of note is the cathodic protection of fourteen offshore drilling platforms in the Gulf of Mexico where over one-half million square feet of submerged surface is protected by a magnesium sacrificial anode system.(19) Magnesium ribbon (Galvoline, Dow) is used to lay down a calcareous coating on the steel surfaces (high current density polarization). A more permanent group of cylindrical magnesium anodes is then employed to maintain protective potentials at low current densities. Figure Number 19 illustrated the effectiveness of coated plates to develop protective potentials and consequently little weight loss (corrosion) at low current densities. When the adherent marine growths become excessive, the application of a high current density will soften the electrocoating and cause the coatings to slough off the metal surface, taking clinging fouling matter with it.

The employment of initial high current density polarization results in ampere-hours savings of 40% for the first year. It is estimated that cathodic protection of offshore drilling platforms of nominal size should cost no more than 6c per square foot per year with a decrease in the average annual cost over an extended period.(19)

Corrosion of underwater steel structures of almost any description can be effectively prevented by the proper application of cathodic protection. The main components of a cathodic protection system are three in number; a cathode, an anode and an electrolyte. At any marine site two of these components are always existant—the salt water electrolyte and the structure to be rendered cathodic. By the addition of a suitable anode system with its connecting wiring, a huge electrolytic cell results which causes electric currents to be impressed on the cathode.

Authorities at the important military establishment, the Panama Canal, have employed cathodic protection for many years to combat the corrosion problem of the lock gates.(49) The initial work, under the direction of S. P. Ewing, was

started in 1940. A system of impressed currents from soluble steel anodes was designed and installed. Early attempts caused slight peeling of the bitumastic paint on the submerged surfaces which was due to poor current distribution. This condition has since been remedied and valuable practical experience gained. Work has been underway to gradually extend cathodic protection to all the lock gates of the canal. Periodic inspection of the reenforced concrete structures which support lock gates revealed no harmful effects due to the calcareous deposition on or near the structure. (50)

The Maritime Commission has a test program in effect which utilizes cathodic protection for the preservation of reserve fleet hulls in sheltered waters. The test ships at the James River and Wilmington, N. C. sites have been under protection for the past year. In part of these tests, polarization of the steel hulls is achieved over a relatively long period of time (2 to 3 months) by using low current producing equipment. In one case, limited capacity rectifiers supply impressed currents to the hulls (electrically coupled in series) from remote impregnated graphite bed anodes located shoreside. Other tests employing magnesium alloy anodes, controlled and uncontrolled, to supply current for protection, considerably reduced the time required for polarization. Once complete polarization of the hulls is accomplished, the use of lower current densities is predicted. Observations that rusted steel hulls require less current density for polarization than clean steel hulls have been confirmed by other investigators. (8) The details of the project have not as yet been released by the Maritime Commission.

The Bureau of Ships is formulating plans to adapt a similar program for the protection of Naval Reserve Fleet hulls.

CATHODIC PROTECTION OF ACTIVE SHIPS

We have cited some evidences of successful applications of cathodic protection to stationary marine structures and its other important uses such as derusting and descaling (at high current densities). Now it remains to determine whether or not cathodic protection and electrocoating techniques can be of practical use in preserving the hulls of active ships in the Navy.

From an academic viewpoint, the subsequent hypothesis is based on a statement by Dr. T. P. Hoar of the Corrosion Research Section, University Chemical Laboratory, Cambridge, England, in his memorandum concerning the NRL report No. P-2389 in 1944.

"The effect of water velocity on the formation of Cox-coatings is a matter of importance which requires further investigation. It should be noted, however, that in practice, ships spend a considerable time in nearly stationary water, and the point is whether or not the coatings formed under these conditions will be destroyed when the ship is in motion."

Hypothesis:

The ship's hull *should not* be painted. Under present conditions, the hull is normally painted for two reasons:

a. To prevent corrosion
b. To prevent fouling.

Many experiments have been conducted that have adequately proven the value of the electrocoating as an anti-corrosive. (9) (10) (11) (15) (19) (46) (50) However, fouling has occurred as readily on an electrocoated surface as on bare metal. (17) (51)

We propose that the anti-fouling phase may be handled in any one of the following methods:

1. At the end of the fitting-out period (at which time we assume very little rusting and fouling of the hull) suitable current densities are applied for a period long enough to economically

form an electrocoating. The ship is then sent out to sea and proper current densities are applied to maintain this coating when the ship is under way.

At the end of the voyage and a port reached, we may expect the loading and unloading of cargo to take aprpoximately seven days. At this time, free-swimming organisms will attach themselves to the coating and fouling will begin. However, if at the fifth day, a high enough current density is applied, (for economic reasons, probably at small sections of the hull at one time) an exfoliation process occurs, taking all fouling matter with it. Peacetime layovers for naval vessels should provide sufficient time to accomplish exfoliation. Under war conditions, naval vessels could slow down in "safe" waters and employ the defouling technique.

2. This method is similar to 1. except that much lower current densities are applied in order to exfoliate the coating; the velocity of the ship under way will tend to wash away the loosened fouling matter.
3. If various factors make it necessary for the ship to go to sea immediately after the exfoliation process, an electrocoating may be built up when the ship is under way. (The procedure, similar to 1.)

Experimental Research can supply the answers to the following important considerations of this phase of the problem:

A. The current density necessary to maintain a protective electrocoating at various velocities (the coating formed in still water).
B. The solubility rates of the electrocoating (formed in still water) at various velocities.
C. The current densities necessary to build up a protective electrocoating on bare metal at various velocities.

The research by independent investigators up to the present has been sparse and no conclusive evidence has been published. Preliminary experiments were conducted on the formation of electrocoatings at high velocities using a revolving disc apparatus. Peripheral speeds of the disc were in the range of 31 knots. The resultant data indicated that a coating could be formed and maintained at "reasonable" current densities.(52) It is extremely difficult to evaluate data recorded under these conditions as the actual velocities involved have not been mathematically determined.

Some experiments to investigate velocity effects of the electrolyte on electrocoatings were attempted at Webb Institute.(53)(54) An apparatus was designed and built and some rough tests were run. No systematic data has been compiled due to difficulties encountered in handling and controlling the test specimens. The knowledge thus gained, was the embryo for further work of this nature at M.I.T. An investigation is now in progress to determine current densities required to polarize and electrocoat bare steel at various velocities of the salt water electrolyte.

Other experiments relating to the frictional characteristics of electrocoatings compared to present standard Navy hull bottom paints were undertaken.(55) The results, on a qualitative basis, indicate that specific electrocoated plates yielded the lowest coefficient of friction while modern Navy plastic paints showed high coefficients of friction. The present high friction surfaces on Navy ship bottoms causes excessive loads on the propellers. The dragging of these friction loads through the water plus the additional cavitation environment imposed by overloading the propellers and the disturbed water flow around the hull, all consume much needed power.

As a result propulsive efficiencies are low. Towing tests of a similar nature are being conducted at the David Taylor Model Basin with painted plates so that a comparative analysis of the frictional characteristics of ship bottom coatings can be evaluated. Several electrocoated panels are planned to be included in the series. The use of towing speeds to produce higher Reynolds numbers (than those at the Webb tank) will add more significance to the data. If electrocoatings can be used on the underwater portion of the hull, these data will materially add to their value.

The Naval Research Establishment, Halifax, a division of the Defense Research Board of Canada, has embarked on several experiments on the cathodic protection of ships underway. The experimentally established criterion for protection of 760 mv., with the anodes in place, was used as a standard comparison in potential measurement surveys to determine whether or not protection was complete. Preliminary trials of two 40-foot steel tugs using magnesium alloy anodes revealed no rusting of the hull despite large areas of exposed steel (56). Inspection of the steel propellers showed the original machine marks on their bright shiny surface after two years service. This may uncover evidence for an electrochemical explanation of cavitation and a method of its alleviation and perhaps complete suppression. Another tug of the same class was fitted with a zinc anode arrangement. Cathodic protection was applied in conjunction with a conventional hull paint system. Although severe paint stripping resulted on the ship fitted with magnesium anodes having no control, little difference was observed in the paint failure between the tug fitted with controlled magnesium anodes and the one fitted with the zincs.(56)

The tug utilizing the zinc anodes failed to achieve protection of the hull or cast steel propellers. The standard zincs used became inactive after several weeks. The 99.9% grade gave much better protection and has been found to be active up to nine months. The Naval Research Laboratory is now conducting actual service tests on four sister destroyers to determine the efficacy of 99.99% high purity zinc as protective anodes for active ships.(57)

The success of the performance of magnesium alloy anodes on active steel tugs led to further installation of cathodic protection to the H.M.C.S. *New Liskeard,* an Algerine Class mine sweeper with an underwater hull area of 7500 square feet. After several unsuccessful short cruises, protective potentials above 830 mv. were maintained for ten hours underway at a speed of 15 knots.(56) It was observed that depolarization of the hull was slight—only a 12% increase in current output from the anodes resulted. The poor performance witnessed during the first month of operations was ascribed to one controlling factor. It appears that the age of the depolarization film governs the severity of depolarization when the ship is in motion.(56)

CONCLUSION

All these investigations point the way toward the possibility of eventually extending cathodic protection to the active fleet. The Corrosion Section of the Naval Research Laboratory, under the direction of Dr. M. C. Bloom and Dr. L. J. Waldron, is now in the process of preparing a research program which is designed to thoroughly investigate and evaluate all phases and related problems of cathodic protection. When the necessary funds are granted by the progressive and foresighted planners of our modern Navy, we may expect to know some of the elusive answers for correct application of a process which has far reaching consequences.

A fertile field of investigation would be the design and installation of permanent hull anodes using an impressed current system for cathodic protection. Extended operations in war-time may create a logistics problem in replacing sacrificial type anodes, and the requirement of wide range current capacity (for all phases of electrocoating and defouling) indicate the need for a permanent anode system. Serious thought should be given to the design of a floating drydock-type platform, carrying an independent flexible anode system, that could service a group of vessels in a given area not having their own anode installations.

It is not in the realm of fantasy to predict the future ship of the Navy with a permanent anode system incorporated in the hull fittings and employing the ship's electric generating equipment as an impressed current source. Corrosion control and defouling may one day be part of the ship's general routine.

To protect our shores we must protect our fleet against the enemy—corrosion. Cathodic protection is our ally.

ACKNOWLEDGMENT

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BIBLIOGRAPHY

(1) T. H. Rogers, "The Influence of Micro-Organisms on the Corrosion of Metals", British Non-Ferrous Metals Research Association, Sept., 1947.

(2) W. H. Vernon. "The Corrosion of Metals", Part II, Journal of the Royal Society of Arts. July 1, 1949. No. 4798. Vol. XCVII, pp. 592, 593.

(3) U. R. Evans, "An Outline of Corrosion Mechanisms Including the Electrochemical Theory", incorporated in "Corrosion Handbook", edited by H. H. Uhlig, published by John Wiley & Sons, Inc., 1948.

(4) F. N. Speller, "Control of Corrosion by Deactivation of Water", J. Franklin Inst., 193, p. 523, 1922.

(5) J. M. Pearson, "Fundamentals of Cathodic Protection", incorporated in "Corrosion Handbook", edited by H. H. Uhlig, published by John Wiley & Sons, Inc., 1948.

(6) May, Schuldiner & Burbank, "Anodec Behavior of Aluminum Zinc Alloys in Sea Water", NRL Report No. C-3277, April 13, 1948.

(7) Dr. T. P. Hoar, "Zinc Protectors for Ships", Final Report ZP-2, Corrosion Section, Metallurgical Lab., Cambridge, England, Nov. 16, 1943.

(8) R. A. Humble, "Cathodic Protection of Steel in Sea Water with Magnesium Anodes", in Corrosion, July 1948.

(9) G. C. Cox, "Some War Applications of the Marine Electrocoating", May 5, 1942.

(10) G. C. Cox, U. S. Patent No. 2,417,064, March 11, 1947.

(11) G. C. Cox, U. S. Patent No. 2,200,469, May 14, 1940.

(12) Sir Humphrey Davy, "Preservation of Metals by Electrochemical Means", from the Philosophical Transactions of the Royal Society, London, 1824-1825.

(13) R. A. O'Brien, Memorandum on Invention of G. C. Cox, January 14, 1941, BuShips, Wash., D. C.

(14) S. P. Ewing, "Galvanic Corrosion of Ships' Hulls", Bureau of Ships, Research Memorandum No. 6-43, date 15 November 1943.

(15) Dow Chemical Company, "Use of Magnesium for the Cathodic Protection of Steel in Sea Water".

(16) Brown and Mears, "Cathodic Protection", 1942. Transactions of the Electrochemical Society.

(17) F. L. LaQue, "Electrolytic Protection of Steel in Sea Water by the Method of Col. G. C. Cox, U. S. Patent No. 2,200,469", October 1942. Report on Corrosion Tests—International Nickel Company.

(18) Col. G. C. Cox, Conversation with Authors, March 9, 1949.

(19) E. P. Doremus and G. L. Doremus, "Cathodic Protection of Fourteen Offshore Drilling platforms", Corrosion, July 1950. Vol. 6, P. 218.

(20) NRL report No. C-3093, April 1947.

(21) H. F. Harvey, Jr., "An Electrolytic Protective Coating for the Preservation of Steel Structures in Sea Water", January 14, 1941 (for the Newport News Shipbuilding & Dry Dock Co.)

(22) G. C. Cox, "The Marine Electrocoating Process", two reports dated December 14, 1940 and December 14, 1941.

(23) R. A. O'Brien, Memo. to BuShips File on visit to the Newport News Shipbuilding & Dry Dock Co., in regard to the corrosion of fouling of "S.S. *President Garfield*", March 25, 1941.

(24) W. E. Blewett, Jr., "Letter to BuShips on the Cox Electrolytic Protective Coating Process at Newport News", June 30, 1943.

(25) J. G. Dobson, "The Control of Fouling Organisms in Fresh-and-Salt-Water Circuits", 1946, Transactions of the American Society of Mechanical Engineers.

(26) J. P. Visscher, "Nature and Extent of Fouling of Ships' Bottoms", Dept. of Commerce, Bureau of Fisheries Document No. 1031, for the Bureau of Construction & Repair, Navy Department, 1927.

(27) W. F. Whedon, Tschudy, and Hindman, "Investigations Pertaining to the Fouling of Ships' Bottoms", Annual Report for 1940-1941.

(28) W. S. Newell, "Latest American Progress in Paints for Use in Ship Construction", Sept. 23, 1946.

(29) Report on Paint Conferences, NYNor 20-22 Sept., 1943.

(30) EES Report NP 16/15/S19 (7344-D) Test B-8513-B dated 10 July 1943.

(31) T. P. May, "Fouling of Cathodicaly Protected Steel in Ocean Water at Kure Beach, N. C.", December 31, 1946.

(32) E. S. Castle, "Studies on the Electrical Control of Fouling", Interim Report No. IV for 1944, submitted by the Woods' Hole Oceanographic Institution.

(33) G. C. Cox and O. J. Streever, "Development of an Electrolytic Exfoliation Process for Interior and/or Exterior Surfaces of Metal Vessels Submerged in Sea Water", Feb. 4, 1941.

(34) Admiralty Corrosion Committee, Hull Corrosion Sub-committee, "Electrolytic Derusting-Preliminary Report", March 17, 1947.

(35) Admiralty Corrosion Committee, Hull Corrosion Sub-committee, "Electrolytic Descaling of Tankers", March 19, 1947.

(36) Admiralty Corrosion Committee, Hull Corrosion Sub-committee, "Some Principles of Electrolytic Cleaning and Their Application to H.M.S. Ships—Second Interim Report", Sept. 9, 1948.

(37) Commander Henry H. Fox, Jr., U.S.N. Code 347, BuShips, Conversation with Authors on March 4, 1949.

(38) Newport News Shipbuilding & Dry Dock Company (for the U. S. Army Transportation Corps) "Reports, Volume IV, Operation 3, Tests 31 through 36", Project 45N-30, November 3, 1947.

(39) Newport News Shipbuilding & Dry Dock Co. (for the U. S. Army Transportation Corps) "Reports, Volume 1, Summary", Project 45M-30, November 28, 1947.

(40) Newport News Shipbuilding & Dry Dock Co. (for the U. S. Army Transportation Corps) "Reports, Volume V. Operations 2, 4, 5, Laboratory Tests", Project 45M-30, April 1947.

(41) Newport News Shipbuilding & Dry Dock Co., (for the U. S. Army Transportation Corps) "Reports, Volume II, Preliminaries, Operations 1, Tests 1 through 5", Project 45M-30, January 1947.

(42) Newport News Shipbuilding & Dry Dock Co. (for the U. S. Army Transportation Corps) "Reports, Volume II, Operation 1, Tests 6 through 16", Project 45M-30, March 1947.

(43) Newport News Shipbuilding & Dry Dock Co. (for the U. S. Army Transportation Corps) "Test No. 51 Exfoliation-Hull", Research and Development Project 45M-30, November 3, 1947.

(44) G. Jones and R. D. Miller, "Report of Electrolytic Descaling of Petroleum Cargo Tanks on USS *Cimarron* (AO22)", April 21, 1948.

(45) Commander Henry H. Fox, Jr. USN "Memorandum Travel Report", February 10, 1948, BuShips, Wash., D. C.

(46) G. C. Cox, "Anti-corrosive Coatings for Tank Ship Compartments", October 14, 1941.

(47) S. P. Ewing, "Memorandum on report of two visits to the Norfolk Navy Yard", June 16, 1942, BuShips, Wash., D. C.

(48) H. A. Humble, "The Cathodic Protection of Steel Piling In Sea Water", Corrosion, V. 5, Sept. 1949, P. 292.

(49) J. A. Miles, "Cathodic Protection of the Lock Gates of the Panama Canal", February 3, 1949. (A paper presented at a panel discussion of the Committee on the prevention of Deterioration and Corrosion at the National Academy of Science, Wash. 25, D. C.

(50) S. P. Ewing and F. J. Amador, "Electrolysis and Corrosion Survey of Gates at Miraflores Locks", Sept. 12, 1940, The Panama Canal Special Engineering Division, Balboa Heights, C. Z.

(51) S. P. Ewing, Memorandum—"Electrical Methods for Preventing Corrosion and Fouling of Ships' Hulls", March 4, 1942, Navy Department, Washington, D. C.

(52) G. C. Cox Private Communication, May 2, 1949.

(53) H. S. Preiser and B. L. Silverstein, "The Effects of Velocity of the Cox Electrocoating" Thesis, Webb Institute, July 1949.

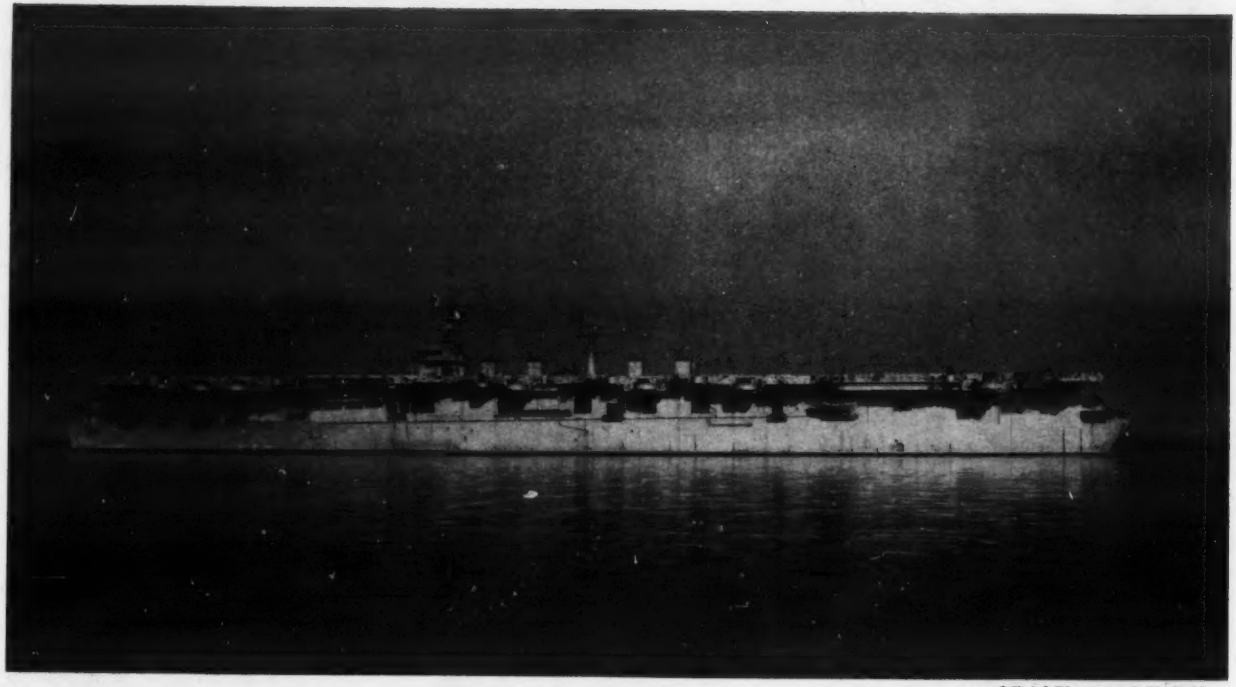
(54) J. N. Spillane and G. W. Wodsworth, "The Erosive Effects of High Velocity Saltwater on the Cox Electrocoating", Thesis, Webb Institute, July 1950.

(55) M. J. Laurier and Carl E. Lindholm, "The Frictional Resistance Characteristics of Cox Electrocoatings compared to Several other Common Underwater Coatings", Thesis, Webb Institute, July 1950.

(56) K. N. Barnard and G. L. Christie, "Cathodic Protection of an Active Ship in Sea Water", Corrosion, Vol. 6, July 1950, P. 232.

(57) NRL ltr. to BuShips, 3500-229/50 ehb (3503) "Report on Inspection of Cathodically Protected Ships of The Royal Canadian Navy", Halifax, Nova Scotia, 12-13, May 1950.

(58) Material Laboratory, N. Y. Naval Shipyard, Final Report 5092, NS 062-034, 14 June 1950.



SMALL AIRCRAFT CARRIER.

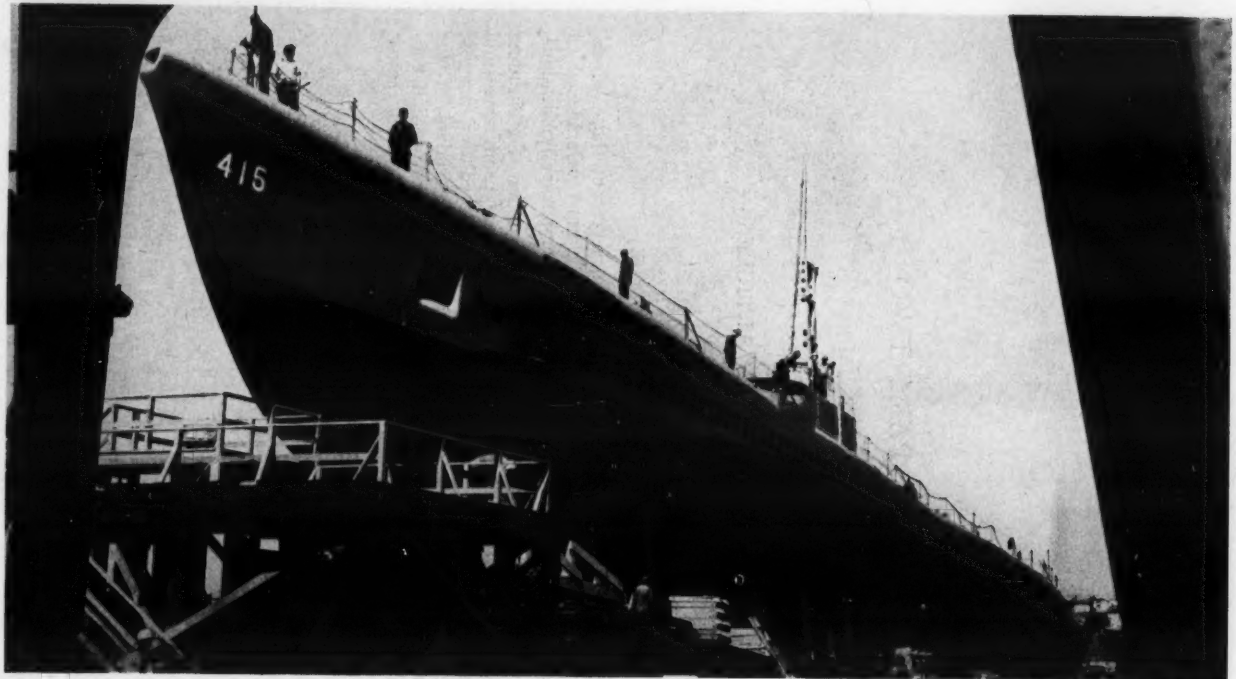
Official Photograph U. S. Navy

PART TWO

REPRINTED ARTICLES

The articles contained in this Part Two represent those which, in the opinion of the editorial staff, are the most valuable which have been gleaned from recent issues of contemporary publications.

This material was formerly published under the heading "NOTES". It has been given somewhat more prominence and made more readable to enhance its value. The editors' purpose here is to provide a convenient repository to readers of the JOURNAL, for articles originally published elsewhere which contribute to the purpose of the Society: to further the advancement of naval engineering.



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SUBMARINE ON THE WAYS JUST PRIOR TO LAUNCHING

POWDER METALLURGY

EARLY WORK IN POWDER METALLURGY

ACKNOWLEDGMENT

Mechanical Engineering for July 1950 contained MR. PAUL SCHWARZKOPF'S article "Powder Metallurgy." The article is a mid-century review of progress in this relatively new field.

Of all those writing mid-century reviews, the physicist is in the best position. For the physicist, the year 1900 really represents the beginning of a new era. In 1900 Planck revealed his quantum theory. Also, it was particularly important for the metal physicist. That same year Drude first introduced the concept of free valence electrons and thus laid the foundation for the modern electron theory of metals.

The position of the reviewing powder metallurgist is almost as fortunate as that of the physicist, provided he ascribes only historical importance to the iron powder-metallurgical implements of the old Egyptians and other agent colleagues of ours, to the platinum of the Incas, and also to the classical experiments of Wollaston. Since this seems justified, modern powder metallurgy may be considered a child of the twentieth century. It was born in 1903, when Just and Hanemann introduced tungsten as material for filaments for electric bulbs. These brittle filaments and similar ones made from molybdenum, used as hooks in these bulbs, were prepared by sintering extruded mixtures of metal powders with organic binders.

When, about 1910, the first publication of the manufacture of a ductile wire from tungsten, produced by normal wire-drawing techniques, appeared, I was already around, and since then I have been continuously active in powder-metallurgical research and production. I have tried my hand in practically all branches of our art, remembering quite distinctly what we learned at each stage and then utilizing this experience to enter and to conquer subsequent stages. This memory might be helpful in predicting to what extent the knowledge accumulated during the first round will act as a decisive and rate-determining factor in the second, that is, in the solution of the problems that we are facing now.

The work required for the development of satisfactory tungsten and molybdenum products needed by the incandescent-lamp industry and later by the electronic-tube industry was a good training for the young powder metallurgist. He not only learned how to prepare, evaluate, and process metal powders, he also observed and systematically studied the effects of powder characteristics, compacting conditions, sintering time and

sintering temperature upon microstructure and mechanical properties, and from these observations he was able to contribute to the theories of recovery, recrystallization, and grain growth.

Prominent among the problems encountered by the manufacturer of electric bulbs was that of "sagging" of his filaments. After recrystallization and grain growth had taken place during service, there were at least some grain boundaries going all the way across the filament which resulted in boundary flow and sagging. This rather serious difficulty was overcome by the addition of agents that either retarded recrystallization and grain growth, or promoted an oriented structure. Through these changes in crystallization, the development of grain boundaries, going all the way across the filament, was counteracted and special overlapping structures were produced which prevented the occurrence of sagging.

All that the young powder metallurgist had learned about things like powder treatment and sintering conditions, he could utilize immediately when he turned from refractory metals to other metallic materials. The knowledge he gained in solving the sagging problem was too specific to find immediate application in other fields. But I believe that this special experience may come in very handy in the near future.

APPLICATION IN HIGH-MELTING REFRACTORY METALS

The high-melting refractory metals are "naturals" for all applications requiring high strength at elevated temperatures. Molybdenum takes the spotlight for these uses. The United States and Canada possess immense deposits of molybdenum ores. Molybdenum is readily workable and machinable and can of late—by coatings which protect it from oxidation and corrosion—be made suitable for applications which utilize its tremendous strength at higher temperatures. Of course for all these uses the operating temperature must be well below the range at which recrystallization indicates high atomic mobility. This means that in the case of pure molybdenum—in the purity degrees obtainable today—the operating temperature should not markedly exceed 900 C or about 1650 F. That is quite high, and a long life of parts at this temperature under high stresses means marked progress.

The jet and rocket engineer is already dreaming of higher temperatures, and powder metallurgy—always eager when requirements are extreme—is trying to keep step with him. It is here where the sagging problem may enter the situation. There can be no doubt that sagging, i.e., flow in crystal boundaries, is related to creep, and agents preventing sagging in filaments may very well also suppress creep in parts such as gas-turbine buckets. However, it must also be kept in mind that small amounts of certain impurities influence properties of molybdenum to a very high degree. In experiments with cast molybdenum, Parke and Ham (1)[1] found that even differences in oxygen contents in the order of 0.0025 percent are of tremendous importance. It is therefore possible that control of purity, that is, the exclusion of the last traces of elements such as oxygen from the grain boundaries, supplemented by the addition of agents which promote controlled crystallization, are imperative in attempts to increase the operating temperature of molybdenum parts. A series of observations also indicates that one of the properties of molybdenum which still restrict the range of its possible uses—its cold-brittleness—will turn out not to be a property of the moly crystals, and therefore can be eliminated.

[1] Numbers in parentheses refer to the Bibliography at the end of the paper.

THE COMPACTION PROCESS

The work with molybdenum and tungsten has been the basic training for the powder metallurgist. In so far as subjects such as the control of powder characteristics were concerned, the young scholar was almost ready for graduation. But there were other subjects. Let us take the compaction process. It must be considered that in the manufacture of tungsten and molybdenum products, the powders were pressed to simple bar shapes only. It was much later, in the production of structural iron and steel parts, that we really learned to press complicated, intricate shapes. Furthermore, we still had to explore techniques such as sintering in the presence of a liquid phase and to learn more about the process of infiltration. Both these techniques were utilized as early as the second decade for the production of composite contact materials which combined the wear and heat resistance of the refractory metals and the high conductivity of lower-melting ones, such as silver and copper. The knowledge of the involved mechanism, at that time, was rather limited. When the powder metallurgist, for example, encountered a system where infiltration did not work, such as cemented carbides, he blamed the system and not his technique.

Recently, the infiltration technique found what is probably its most important practical application in the field of ferrous structural parts. During this development, it came about that the course taken in the second decade had been one for beginners only. Today we know how to infiltrate systems which previously could not be treated by this technique. More of this will be explained later in the paper.

DEVELOPMENT OF CEMENTED CARBIDES

The third decade brought the development of the modern cemented carbides. It started in Germany, when a substitute was needed for the diamond drawing dies for the wire-producing industry. The carbides of the refractory metals were found to have the required hardness and wear resistance. H. Lohmann was the first who produced drawing dies from tungsten carbide by melting and casting. That was in 1914, already in the second decade. The cast dies were typical "ersatz" products. Satisfactory control of composition and quality could not be achieved. Lohmann himself tried to overcome his difficulties by replacing casting with sintering of pressed bodies from tungsten-carbide powder. The improvement was not marked and—as already mentioned—attempts to apply the infiltration technique for the introduction of a binder material also failed.

The problem of consolidating carbides was solved finally when, in the early 1920's, Schroeter developed his method of sintering in the presence of a liquid binder metal phase. Tungsten carbide, cemented according to Schroeter with various amounts of cobalt, proved highly satisfactory as material for wire-drawing dies, wear-resistant parts, and as cutting tools, e.g., for gray cast iron.

The cemented tungsten carbides now on the market are practically identical with the material introduced by Schroeter. The advent of his cemented tungsten-carbide tools initiated a revolution of the machining technique. However, the applicability was still limited to the machining of rather brittle materials, such as the gray cast iron mentioned, which upon machining yield short, crumbly chips. For tougher and stronger materials, particularly steel, which give long chips, the tungsten carbide-cobalt materials, as well as tantalum-carbide materials containing also only one carbide, were not satisfactory. For these most important applications it was necessary to develop other cemented carbides.

We found that solid solutions—mixed crystals—of two or more carbides were necessary to meet the requirements for cutting long-chipping materials.

Since 1929, WC-TiC-Co and similar double or triple-carbide tools have been used successfully for the high-speed machining of steel and similar tough materials. The part played by the new tools in the armament race at the beginning of the last war is generally recognized, and certainly one of the most striking testimonials that can be given the achievement of powder metallurgy.

Today we have an ample supply of data on the crystal structures of the compounds involved, on the mutual solubilities of carbides, and on the sintering mechanics. Thanks to the work of men like Comstock, Norton, and Redmond in this country, Brownlee, Metcalfe, and Raine in England, Kieffer and Nowotny in Austria, Dawihl in Germany, and Meerson and Umanski in Russia, to name only a few, these are well-established facts today.

Not many of these data were available when I started my work with solid solutions of carbides. Fortunately, enough was known to center the interest on systems containing TiC as additional carbide, and it is rather satisfying to note that the multiple-carbide tools used today are essentially identical with those made twenty years ago. Since, however, materials such as WC-TiC-Co compositions contain excessive amounts of scarce elements, which are found only at a few points of the earth's surface, my last statement is an admission of failure. We certainly tried hard to replace tungsten and cobalt with more readily available materials. We did not succeed. The substitutes developed during the war in Germany—mostly solid solutions of titanium carbide with carbides of metals such as vanadium—had rather limited applications. As previously stated, it is a failure, but in a way this failure is satisfying.

The question I should like to raise at this point is whether or not we can expect, in the years to come, progress in the cemented-carbide field—progress going beyond the developments which are associated with the name of McKenna, and represent the first practical application of cemented carbides in the high-temperature field. I firmly believe that my optimistic view in this respect is more than just wishful thinking. To support this view let us consider some aspects of the theory involved.

THEORETICAL CONSIDERATIONS

The carbides we are interested in are all compounds of carbon with metals of the so-called transition groups of the periodic system. If the ratio of the atomic diameter of the C atom to that of the metal atom is less than about 0.59, then the carbide represents, according to Hägg, an ideal interstitial alloy. The metal atoms are in a simple close-packed arrangement and the C atoms fill the interstices of the lattice. In mixed crystals of different carbides, we have the interesting case of an alloy which is substitutional and interstitial at the same time. The metal atoms, taken by themselves, form a close-packed substitutional alloy with the interstices filled with the carbon atoms. But this well-established structure is only one side of the picture. It shows how the atoms are arranged with respect to each other, but it does not show how the atoms are bonded together. We became accustomed to the concept that the close-packed metal atoms in interstitial phases are held together by metallic bonds. But there seems to be no general consensus of opinion.

To give an example, in a recent paper (2), I found to my surprise that carbides were being classified as ceramics. The author clearly stated what he meant

when he referred to ceramics: "Any material that is neither organic nor metallic." I do not know what ceramists think of this definition. I have no objection to it, but I believe the statement is meaningless without giving a definition of a metal. If, e.g., the positive temperature coefficient of electrical resistivity is taken as a criterion, then our carbides represent typical examples for metals. We cannot deny the close relationship between ceramics and powder metallurgy, and we gratefully acknowledge that powder metallurgy learned much from the older techniques of the ceramic industry. More than that—we are prepared to go on learning from the ceramist wherever we can, and we shall acknowledge this. But the ceramist is mistaken when he thinks he can claim the carbides as a fee for his teaching.

In any case, the low thermal and electrical resistivities and the positive temperature coefficient are characteristic properties of the carbides. The resistivity of some interstitial alloys is even lower than that of their transition-metal components. This is interesting from the viewpoint of the electron theory of metals. The resistivity of all transition metals is comparatively high, and this is explained by the electron theory of metals as being due to the high density of quantum states in the only partially filled d-bands of the transition metals. From this viewpoint, it could be assumed that electrons from the interstitial carbon atoms lessen the number of available d-states, and thus increase the conductivity of the carbides above the value of the pure transition metals.

These arguments represent a strong support for the assumption of metallic bonds in interstitial phases. However, the problem is more complex than indicated so far. Following Pauling and Rundle, it seems necessary to accept—in addition to metallic bonds—the presence of directed bonds in interstitial carbides. Pauling's theory seems especially fitted for application to interstitial compounds, and I am afraid we shall have to get used to half bonds and similar concepts of his theory. The metal physicist cannot and does not overlook successes of Pauling's chemical theory of the metallic bond, such as the interpretation of the magnetic characteristics and high melting points of the transition metals. The physical chemist, on the other hand, should not overlook that Pauling, so far, has not been able to extend his theory to semiconductors. Sooner or later, the physical metallurgist and the physical chemist will have to find a common language. Their closest approach to each other, so far, is to be found in the theory of the transition metals, and it may very well be that the final union will be accomplished in the theory of interstitial phases.

THE PRACTICAL APPROACH

The practical man has not the time to wait for the final theory. He has to go ahead on the basis of the fragments so far supplied, and he might be able to do so. I indicated how little data on crystal structures were available when we succeeded in developing the modern carbide tools. So it may well turn out that the little knowledge we have today of the electron and bond structure will point correctly to the direction we have to follow in our present and future work.

There are reasons to expect that interstitial carbides are particularly promising in so far as high-strength requirements at high temperatures are concerned. The high melting points and the high moduli of rigidity are among the criteria pointing in this direction. I am speaking now of pure interstitial carbides and solid solutions thereof, and not of the standard cemented-carbide materials. Standard cementing methods which are satisfactory for the manufac-

ture of tools and wear-resistant parts reduce the hot strength. To utilize fully the inherent high-temperature strength of the carbides, it will be necessary to design new cementing procedures. There are reasons to believe that this can be done. But in so far as applications such as the use as gas-turbine buckets are concerned, this would represent only a partial solution. If we aim at operating temperatures markedly in excess of today's, we cannot dare to expect that carbides will meet with the second main requirement of high-temperature materials, namely, that of resistance to corrosion and, particularly, of resistance to oxidation. It would be necessary to provide the carbide materials—like the refractory metals—with corrosion-resisting coatings.

There is no question but that it is preferable to use materials meeting both requirements: that of strength and that of oxidation resistance. The hot strength of interstitial carbides is, no doubt, closely connected with their structure, that is to say, with the arrangement of the atoms as well as with the nature of the bonds between these atoms. Substances of a similar structure therefore could be expected to exhibit an equivalent hot strength. It appeared worth our while to scrutinize the list of such substances for some which might, in addition to hot strength, also be of high corrosion resistance.

We found that the most promising compounds were commercially not available, and thus it became necessary for the powder metallurgist to enter the field of preparative inorganic chemistry. This proved a successful detour. I am glad that I am permitted to mention a recent Navy release which revealed that a new material, based upon zirconium boride, withstood higher temperatures on the test stand than any other material. This new product has been developed following the ideas mentioned.

All this is a beginning. It is too early to predict the field of application for which the new material will prove most advantageous, but it is at least possible that these fields will include—besides high-temperature uses which are in the foreground—also a new group of machining tools.

INTERMETALLIC COMPOUNDS

There is another field in which the powder metallurgist has come in close contact with intermetallic compounds. In the search for coatings which would make refractory metals resistant to oxidation at high temperatures, it was found that in several instances the formation of intermetallic phases, such as silicides, is essential for effective protection. One of the next steps in research will be the study of those intermetallic phases. Some of these phases may be electron compounds, others may be co-valency compounds, and still others even ionic compounds. This is virgin territory. The phase diagrams involved will have to be established, and the structure of the intermetallics must be correlated with the properties. It may very well be that some of these intermetallics can be bonded by methods of powder metallurgy and would represent in this form satisfactory high-temperature materials.

So far, theory is not offering much help in this line. Since the systems under consideration contain metals of the transition group, it can be expected that any structure which might be established experimentally will be explained by the theory. The Pauling theory will do that by postulating suitable resonance effects, and the electron theory of metals will also be able to offer an interpretation since, according to this theory, transition metals may have different valencies in different combinations so that it will not be difficult to postulate a valency in agreement with the experimental results.

Unfortunately, the man of practice is less interested in such explanations than he is in predictions.

It should be admitted that in this connection the term intermetallics is used somewhat loosely. We do not know whether all the compounds under study are actually metallic in character. It may very well be that some of these compounds must be classified as ceramics.

DEVELOPMENT OF FERRITE MATERIALS

Speaking of ceramics, we should mention here a very important development in the magnetic field, which involved the use of powder-metallurgical techniques, namely, the development of the ferrite materials. With the development of these soft magnetic materials of high electrical resistivity, Snoek succeeded in practically eliminating eddy losses in high-frequency applications. This problem could not be solved with pure-metal powders. If the ceramist claims these oxides, it is hard to find a logical basis for an objection. In any case, techniques of powder metallurgy permit us to handle the oxide powders and to produce ferrite materials.

Sintered mixtures of metal powders with powders of oxides or other ceramic materials have recently attracted the interest of the powder metallurgist as well as that of the ceramist. Terms such as "ceramels," "ceramets," and "cermets" have been suggested for this class of products. Some of the workers in this field think in terms of electrical applications. Such mixtures also have been tested, without appreciable success, for tool materials. Most important, however, appears the potential use of these materials for high-temperature purposes. In applications such as turbine blades, ceramic oxides usually fail on account of their low resistance to thermal shock. It very well may be possible that the incorporation of suitable metals may impart to these products the required thermal-shock resistance.

When one sinters a mixture of, say, aluminum oxide and iron powders, he is at liberty to consider the sintered mixture as iron-bound aluminum oxide. This point of view clearly demonstrates the close relationship between oxide-metal combinations, that is, cemented oxides, and our cemented carbides. This is a problem where the ceramist can utilize the experience gained in the development of cemented-carbide materials; in other words, where the ceramist can learn from the powder metallurgist.

MANUFACTURING COMPOSITE CONTACT MATERIALS BY INFILTRATION

Another important development in the chronology of the powder metallurgist is that of the composite contact materials.

Manufacturing composite contact materials by infiltration, we had first to prepare porous skeletons of the high-melting components. At that time we learned the fundamentals of how to prepare parts of controlled porosity. The powder metallurgist began his advanced course in this art at the beginning of the fourth decade in the mass production of porous bronze bearings, which today is one of the most important phases of our industry.

We became skillful in the art of producing parts of closely controlled porosity through achievements such as the mass production of the porous nickel cup which was the safety device of the proximity fuse. This miraculous fuse played a decisive part in Britain's defense against the V-bombs, in the Battle of the Belgian Bulge, and in the defeat of the Japanese suicide bombers, and thus contributed largely toward shortening the war. It has been claimed re-

peatedly that the proximity fuse surpassed in practical importance all other wartime inventions, and this claim may very well be justified.

Further developments in the field of porous parts which must be mentioned, since their principle may be useful in future applications, are the iron projectile-driving bands—a German war development—and the aircraft deicing equipment, a British development.

An interesting new field for porous powder-metallurgical parts had been opened by the so-called sweat or transpiration-cooling method as developed by Duwez in the Jet Propulsion Laboratory of the California Institute of Technology (3). Duwez is forcing a cooling liquid through porous metal parts in a direction opposite to that of the heat flow. This procedure permits very marked increases in operating temperatures and may be expected to find wide and important uses.

So far, this review has been limited essentially to so-called noncompetitive products, that is to say, products which cannot be manufactured by any method other than powder metallurgy. This is true for the refractory metals which have a melting point too high for other processing methods; it is also true for composite contact materials, for cemented carbides, and for parts of controlled porosity.

POWDER METALLURGY ENTERS THE COMPETITIVE FIELD

At the beginning of the 1940 decade, the powder metallurgist had learned enough to try his hand also in the competitive field. His technique was advanced enough to be employed in the production of parts—especially iron and steel parts—which could be and, in most cases, were previously manufactured by standard metallurgical procedures. In order to be able to compete, the products of powder metallurgy had to be less expensive than the standard cast materials. The powder metallurgist had to find the most economical production methods. The classical investigation of Sauerwald and his co-workers, published in the 1920's, supplied valuable data revealing the effects of compacting and sintering conditions on the characteristics of iron compacts.

In the early 1930's, the attempts of the German industry to find a use for carbonyl iron had further increased our knowledge. But these were experiments carried out with iron powders of high purity under laboratory conditions. It was a long way from the laboratory to mass production based on commercial powders. The price of these commercial powders was—and still is—high as compared with the raw material of our competitors. We have to overcome this handicap, and in order to do so, we must make full use of the fact that powder metallurgy permits us to make parts in final shapes and thus to save cost of machining. The more complicated a part, the higher are the savings.

The powder metallurgist thus had to become a master in the art of compacting powders to complicated shapes. The progress made in this direction during the last years is outstanding. As an example, Fig. 1 shows a compressor blade for jet engines that is now being mass-produced by powder metallurgy based on developments carried out by my company in collaboration with Thompson Products (4). The tolerances we had to maintain in this case were extremely close. The differences in thickness between the thin trailing edge and the root will be noted, as well as the fact that the blade is twisted.

We had to go a long way until we were able to meet the strength requirements of the compressor blade. For help in future developments in the competitive field, it may be permissible to describe more in detail this phase of our work (4, 5, 6).

HOW COMPETITIVE PARTS ARE PRODUCED

In principle it is possible to produce sintered parts having the same strength as cast and wrought materials of corresponding composition. All we have to do is to eliminate all residual porosity. As long as we have pores, we have notch effects and inferior strength. This must be admitted. For a large number of purposes, this inferior strength is still far in excess of the requirements. However, for high strength, we have to get rid of that residual porosity. As soon as we succeed, we have powder-metallurgical parts that are as strong as the corresponding cast and wrought materials. Furthermore, owing to the advantage of easier control of purity and boundary conditions, these parts may be even stronger.

Practically pore-free bodies may be produced by hot-pressing or repeated cycles of compacting at high pressures and sintering at elevated temperatures. But these procedures are too expensive for products in a competitive field. There is reason to expect that future developments will lead to economical hot-pressing techniques, but, so far, such techniques are not available.

It was the experience in the production of composite contact materials that indicated another, more economical, way to arrive at a pore-free condition; that means sintered parts of high strength. Sintered iron or steel skeletons were prepared having a porosity of about 15 percent by volume, and the pores were filled by infiltrating a liquid copper alloy. Table 1 shows the strength values which we were able to obtain in mass-production runs.

In order to reach the remarkable tensile properties listed in the last column of the table, it was necessary to design a special heat-treatment to strengthen the ferrous as well as the cuprous phase by precipitation-hardening.

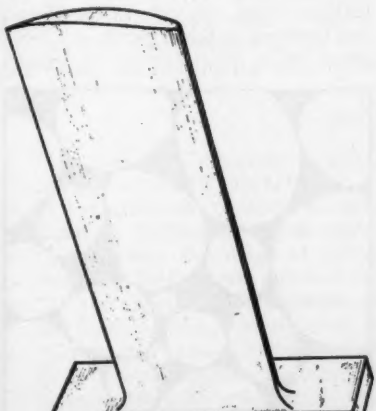

FIG. 1 COMPRESSOR BLADE FOR JET ENGINE

TABLE 1 EFFECT OF HEAT-TREATMENT ON SOME MECHANICAL PROPERTIES OF INFILTRATED IRON AND STEEL*

(The ferrous skeletons of all specimens were pressed and sintered to 85 per cent density. Complete infiltration of all specimens then left them virtually free from residual pores)

		As infiltrated[b]	Solution-heat-treated[c]	Precipitation-hardened
Fe-Cu[a]	Yield strength, psi	62,200	61,300	75,400
	Tensile strength, psi	67,500	71,700	81,900
	Elongation, %	3.3	6	3
	Area reduction, %	3.3	6.6	3.5
	Rockwell B	95.5	82	92.5
Fe-Cu-Mn[a]	Yield strength, psi	89,500	70,500	87,100
	Tensile strength, psi	91,800	84,600	93,500
	Elongation, %	1.3	5.3	2.6
	Area reduction, %	0.82	7.0	2.4
	Rockwell B	96.5	89	91.5
Fe-Cu-C[f]	Yield strength, psi	72,900	71,300	78,500
	Tensile strength, psi	76,100	76,700	79,500
	Elongation, %	1.6	3.0	2.3
	Area reduction, %	2.1	6.0	3.8
	Rockwell B	88	101	89.5
Fe-Cu-C-Mn[e,f]	Yield strength, psi	95,200	88,500	93,900
	Tensile strength, psi	95,200	92,900	94,700
	Elongation, %	1.3	2	1
	Area reduction, %	0.82	1.63	0.82
	Rockwell B	96	94.5	91.5

[a] After pressing and sintering to 85 per cent density, specimens were infiltrated with a mixture containing 98 per cent electrolytic copper and 2 per cent iron.

[b] Infiltrated at 2125 F for one hour.

[c] The infiltrated specimens were heated to 1300 F for one-half hour and then to 1600 F for one-half hour and finally quenched in oil.

[d] After solution heat-treatment, the specimens were precipitation-hardened by holding at 930 F for one hour.

[e] The infiltrant was a mixture of 90 per cent copper, 2 per cent iron, and 8 per cent manganese.

[f] Graphic (0.25 per cent) was added to the iron powder prior to compaction.

* Courtesy of *Metal Progress*, January, 1950 (6).

MECHANISM OF INFILTRATION PROCESS

During this work we learned much about the mechanism of the infiltration process. Today we consider this procedure as a sequence of the following steps (6):

1. Sintering in the absence of a liquid phase.
2. Infiltration.
3. Sintering in the presence of a liquid phase.

The success of the infiltration technique is, to a large extent, due to the fact that it permits the combination of the advantage of sintering in the absence and sintering in the presence of a liquid phase. The accompanying schematic drawings may serve to illustrate this point.

During sintering of iron in the absence of a liquid phase, the pores tend to spheroidize, as shown in Fig. 2. Spheroidization of pores is accompanied by the establishment of large contact areas. It will be understood that a structure approaching that shown in Fig. 2 will be observable only after long sintering at high temperatures. However, the tendency to spheroidization and thus toward establishment of large contact areas will always be there as long as sintering takes place in the absence of a liquid phase.

When we sinter ferrous skeletons in the presence of a liquid cuprous phase, on the other hand, we observe a spheroidization of the ferrous particles as schematically shown in Fig. 3. This spheroidization counteracts the establishment of large contact areas between the iron particles. The larger the contact areas, the stronger the bonding. From this viewpoint, sintering without a liquid phase would seem superior; but there are other factors to be considered. Aside from the practical elimination of residual porosity, the liquid phase brings additional advantages. When we sinter a homogeneous metal-powder compact below the melting point of the metal,

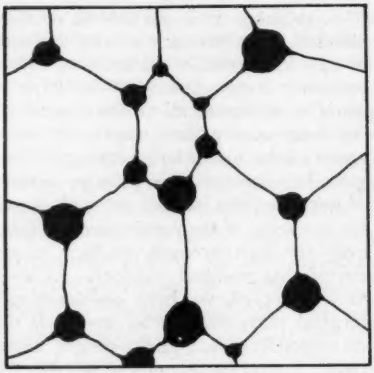

FIG. 2 PORES SHOWING SPHEROIDIZATION IN ABSENCE OF LIQUID PHASE

the rearrangement of the atoms takes place by a bulk-diffusion or viscous-flow mechanism. When we sinter an iron skeleton in the presence of a liquid copper alloy, atomic rearrangement may also be effected by a mechanism of solution and reprecipitation. No calculations are available, but it may very well be that this mechanism is more effective than that aforementioned.

In any case, there is no doubt that both processes, sintering in the absence and sintering in the presence of a liquid phase, have their distinct advantages.

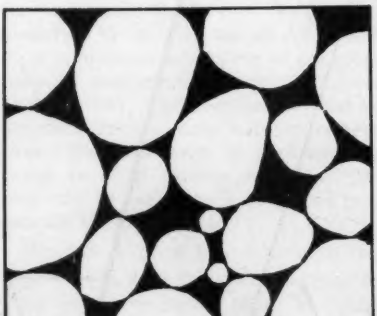

FIG. 3 SPHEROIDIZATION OF FERROUS PARTICLES IN PRESENCE OF LIQUID CUPROUS PHASE

The advantage of the first process is the establishment of large contact areas. When we now sinter first without and subsequently with a liquid phase, we can assume that the contact areas established during the first step will not be disrupted by the subsequent introduction of a liquid. A structure as indicated in Fig. 4 will result. The infiltration technique thus offers a possibility of combining the beneficial establishments of large iron-to-iron contact areas with the well-known advantages of sintering in the presence of a liquid phase.

The new application of the infiltration technique permits the economical production of high-strength structural parts by powder metallurgy. Further expansion in this direction is imperative.

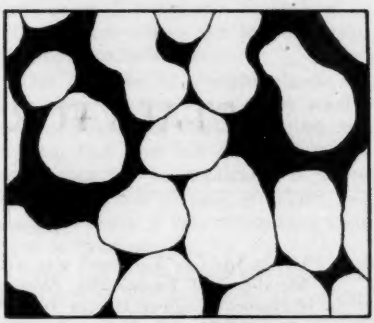

FIG. 4 STRUCTURE RESULTING FROM FIRST SINTERING WITHOUT AND THEN WITH A LIQUID PHASE

CONCLUSION

In outline, this is the course of developments which led from the manufacture of ductile tungsten and molybdenum to the production of composite contact materials, cemented carbides, porous parts, and high-strength structural materials. The accomplishments made in this art appear rather impressive.

The potentialities of powder metallurgy are far from being utilized fully. As we used the experience gained in, say, the 1920's, for our work in the subsequent decade, so we shall be able to use the experience gained in the first half of the century for the work to be done in the second half.

I have expressed my belief that, with the aid of powder metallurgy, it will be possible to solve one of the most urgent engineering problems of our day, that is, the development of materials exhibiting satisfactory strength and corrosion resistance at extremely high temperatures. I fully realize the risk involved in predictions of things to come, but I sincerely believe the foundations laid by the work of the powder metallurgist in the past half century are sound enough to justify the optimism expressed in this preview.

BIBLIOGRAPHY

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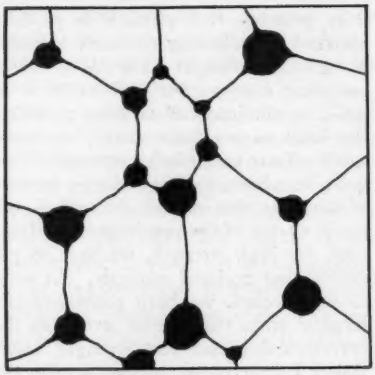

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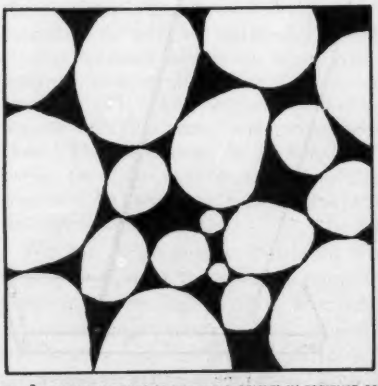

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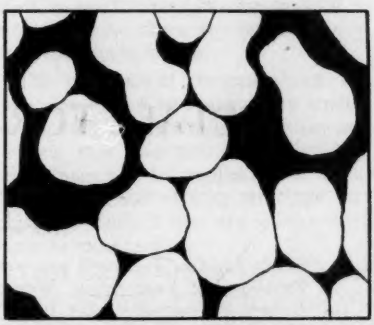

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METALS FOR GAS TURBINES

ACKNOWLEDGMENT

"Metals for Gas Turbines" was written by MR. NORMAN L. MOCHEL, Manager of Metallurgical Engineering, Westinghouse Electric Corporation. It appeared in Mechanical Engineering for June 1950. It discusses metallurgical development of gas-turbine applications with emphasis less on the aviation field than on transportation, stationery power plants, etc.

Three and a half years ago, at the Detroit meeting of this Society, the author discussed (1)[1] certain metallurgical considerations of gas turbines. In that discussion he referred to gas turbines for many applications. Some were relatively small and had very short life, as compared with others that would be much larger and necessarily would have to render many more hours of service. He emphasized the very important part that expected life must have in the development, evaluation, and selection of materials for successful application in all types of gas turbines.

In the few years since that time, the greater part of the development and evaluation of gas-turbine materials has been in connection with jet engines and propjet drives for aircraft. Not too much fault can be found with this fact. It was fully expected that the major developments and activity would continue in that field. There was and is the matter of national defense. There was the fact that many engines were to be built, and any manufacturer of gas-turbine alloys and parts had far greater opportunity to sell his product in that field, and possibly recover some of his development costs, than by looking at the very few larger gas turbines that were being built or contemplated.

There was more interest, and that means more money and people available for materials development and study, in the aviation field. The interests of the Navy Bureau of Aeronautics, the Army Air Forces, the National Advisory Committee for Aeronautics, the four principal jet-engine builders, and the several aircraft manufacturers, would assure activity. The work of the Society of Automotive Engineers is creating "AMS" specifications for high-temperature materials for aviation gas turbines has been an important contribution. Through its Subcommittee on Heat-Resisting Materials, the NACA provided the best clearinghouse for data and studies on all phases of gas-turbine materials development. The formation of an active Aviation Panel in the ASME-ASTM Joint Committee on the Effect of Temperature on the Properties of Metals provides a further center for concerted planning and evaluation.

It is worthy of comment that there has

[1] Numbers in parentheses refer to the Bibliography at the end of the paper.

been excellent cooperation on the part of so many individuals, companies, government departments, and research groups, in the advancement of our knowledge of these materials. Most have looked upon the matter as one of national effort and advancement, and have freely offered their data, their personnel, and their facilities to a common improvement.

One can hardly escape the impression that the greater part of the facilities, minds, and materials of our alloy-development sources, the greater part of our testing facilities and personnel, and most of our best evaluating minds, have largely been employed through these years in developing materials for comparatively short-life apparatus, jet engines, propjets, ramjets, rockets, and the like.

Many of those interested in gas turbines for other purposes than aviation have had to depend very greatly on the aviation developments. While it may be carrying things too far to liken them to Lazarus eking out a living from the crumbs that fell from the rich man's table, nevertheless there has existed too much of a feeling at times that all of the needs could be derived from the aviation developments.

It is the real purpose of this discussion, then, to try to stimulate more thought and activity in metallurgical development of gas-turbine applications in other fields than aviation, such as for transportation both in ships and locomotives, for oil and gas-pumping service, and for stationary primary power purposes.

Such applications immediately suggest problems and the need for information that can hardly be supplied by the aviation studies. Long expected life running into years, the corrosive effect of cheaper and poorer fuels over those longer periods of time, and the resulting effect on the rupture and fatigue properties of the materials as a time matter, the need for larger pieces of material than heretofore produced, and the question as to how well the properties developed in small pieces can be realized in larger pieces—these are but a few of the problems before us.

The question of thermal shock has been considered by many. But studies and conclusions arrived at in sizes and designs that live but a few hundred hours may not be applicable at all to larger sizes and varying structure that must last years, if they are to earn their right to existence.

There has not been the same opportunity for material developers and evaluators, if I may use such terms, to get together and compare notes, and benefit from each other's experiences, as has existed in the aviation activities. This is understandable. In general, there has not been the same recognition of any national defense, nor of an over-all national effort, such as appears to exist to some degree at some places abroad, in all phases of gas-turbine development.

Possibly the creation of the Gas Turbine Power Panel of the ASME-ASTM Joint Committee on the Effect of Temperature on the Properties of Metals may offer the place for an ethical, yet fairly free, discussion of the problems before us. Already, research plans are being studied. These studies will sooner or later require financing, if they are to go forward.

It is believed that a critical look at our present position as regards metals for long-life gas turbines has some merit. There are some interesting risks involved when anyone attempts a critical evaluation of the supposed present position in a rapidly developing field. He may readily be accused of not knowing what he is talking about. It is obvious to anyone who has been seriously engaged in gas-turbine metallurgy that few persons, if there be any, really know of all the investigations that are under way. Much information is still classified as secret, confidential, or restricted. One just does not talk about many matters.

No doubt some alloy-development groups and some engine builders have developments under way, or nearing completion, that they prefer to keep to themselves for a while. Perhaps the very metals that we need, or the data that we need so badly, are there, right around the corner, and we do not know it. It could be, but we have no reason to believe that it is so.

A critical review or outlook should not be too critical; it must by all means be constructive.

Quite often the author has heard a complaint voiced by a number of those actively engaged in the development and evaluation of these high-temperature materials that if they knew better what was wanted, what the designers were thinking of, what the designer really wants as regards test data, perhaps they could make their contribution more intelligently and thus more effectively, than they may appear to do at present. Society meetings offer a forum for this purpose.

SURVEY OF LONG-LIFE GAS TURBINES

Recently there appeared in the technical press a survey (2) of all the long-life gas turbines in operation, built or building, or under design. This survey is an excellent one for study by those engaged in material development. If one overlooks the "experimental and shop units" for the time, there are listed some 27 stationary units, 10 locomotive units, and 6 marine units. No doubt there are additional items that have been added since the survey was made, and it will be appreciated that there are some few others of a secret or confidential status that were not listed.

The United States part, 7 of the stationary units, 6 of the locomotive units, and 3 of the marine units should be noted. More important, it will be observed that the United States designers are aiming at higher inlet temperatures, in general, than those abroad. In the stationary field, it is 1350-1400-1500 F in the United States; 1200-1250 F in England; 1000-1250 F in Switzerland; and 865-1300 F in France. Eleven units ranging from 1200 to 27,000 kw at inlet temperatures of 1000-1100 F, on the part of one Swiss concern, cannot escape the notice of metallurgists interested in this subject. The pattern as regards temperatures is well set forth. The general characteristics of these gas turbines have been listed in considerable detail, and are worthy of study by metallurgists and others engaged in materials evaluation. Relative size, inlet temperature, speeds, general construction, whether cooling is employed—these are matters for the metallurgist to observe and consider.

GENERAL MATERIALS CONSIDERATIONS

In considering materials for gas turbines, it may be helpful to group the necessary materials into two general classes:

1. The high-temperature metals necessary for a comparatively few "hot" parts, such as the combustion liners, the hot casings and ducts, high-temperature bolts, the rotor of the gas turbine, and the turbine blades or buckets.

2. All those other materials for compressors, gears, auxiliaries, heat exchangers, etc., that probably are available in sufficient development for our present needs.

For the immediate purpose, it is believed the second class may be disposed of rather briefly.

The need for bigger and better aluminum-alloy forgings has been men-

tioned before. Some improvements have been made. But the desire for aluminum alloys for higher temperature service than available before appears to have faded as there came the realization that aluminum alloys were probably never meant for those higher temperatures. Improved ductility is definitely desirable.

Instead there has been a surging interest in titanium and titanium alloys, and there is every reason to believe that these materials, despite their high cost, will find prompt application in jet engines and the like. High cost and low production will probably prevent their use in other gas turbines for the present.

Interesting and complex corrosion problems have arisen in connection with various heat exchangers for gas turbines. A wide variety of materials in the necessary shapes, such as tubes, sheet and plate, are available, and should readily meet the conditions, as they become better understood. The use of salt-laden air may also introduce problems of corrosion into the compressor, and other parts, during shut-down conditions. This, however, is no new problem, and there are ways of taking care of it.

Let us turn, then, to the hot parts of the gas turbine, and see what progress we have made with them.

COMBUSTION LINERS

In 1946 the author pointed out (1) his belief that, in general, reasonable service life for combustion-chamber liners would be accomplished more through careful and ingenious design than merely by seeking more and more resistant materials. This has been confirmed. Inconel and 25/20 chromium-nickel steel are still largely favored for the purpose. Examination of these materials after 1000 hr of life shows negligible attack, and no reason for not expecting long and undisturbed service. Indeed, liners made of several superalloys did not behave so well.

TURBINE CASINGS AND DUCTS

One naturally thinks of castings, forgings, and welded construction for these parts, depending on sizes, shapes, pressures, and the other features present. It is believed that difficulties of procurement and manufacture are far more important at this stage than the material itself. Existing materials appear adequate. Difficulties have been encountered by some builders in getting good sand castings. Some attempts have been most discouraging.

Actually, forgings have been used by some builders. While high in first cost, they are often much more economical in the end than castings. The pattern cost is avoided, and much time and expense of repairing steel or alloy castings is eliminated. Also, heavy plate sections are difficult to procure, in the limited quantities wanted, and forgings again must be employed for these needs.

On the other hand, quite excellent centrifugal castings have been made available in a wide range of sizes for aircraft-engine applications, and offer much for long-life turbines as well.

Real progress has been made in building up casing members by welding together forged parts, some cast parts, especially centrifugal castings, plate and sheet.

HIGH-TEMPERATURE BOLTING

One has a choice of a number of bolting materials that have already been used to some degree in service, although for short periods of time. Steam-turbine practice has employed the alloys EME and N-155 at actual temperatures of 1050 F for over a year. The nickel-base alloys, such as K-42-B and Inconel-X, have been used for various time periods at 1000 F to 1200 F, and even higher. The alloys N-155, S-590, and S-816 have been used to some degree, at higher temperatures. One observes a growing demand for more and better data on these and other bolting possibilities, as to their relaxation behavior over long periods of time; how susceptible are they to cracking at the root of the threads, or under the heads, how tightly should they be pulled up; how brittle do they become after long service exposure; how many times may they be retightened?

TURBINE ROTORS

In the author's opinion, the rotor of the long-time gas turbine presents the most important metallurgical consideration of the moment.

In the case of jet engines, most of them employ a single disk rotor, and some of them, especially the larger ones, have two separate disks secured together by bolting. There has not been much change in the disk alloy since the first engines. Timken alloy and the 19-9-DL alloy steel are still largely employed for the purpose. The composite disk made up of a ferritic steel center with a rim of Timken alloy welded to it has been successfully employed in several engines, and this approach is growing in over-all interest. The British G-18-B alloy has found its way into American practice, but its continued use is somewhat questionable. The Discaloy alloy is now in the process of adoption and use on a broad scale, in order to meet the demands for a better material. Greater advances have been made in improving the quality of the existing alloys in disk form than in making new ones. Greater strength, greater ductility, improved soundness, improved over-all reliability of the exciting alloys have been realized. The Kellogg process (3) for the production of improved ingots for disk manufacture is growing in favor. Contour forging of the disks in specially developed dies has increased reliability. Disk failures are a thing of the past.

In the jet-engine field, one hears the oft-repeated, half-joking, half-serious, remark "over alloyed," as regards disks in our current engines. There is much serious thought being given to a reduction in the amount of critical materials that are used in disks. Some ferritic materials are being seriously considered. An extension of the use of the composite disk is under consideration.

As to larger and long-life gas turbines, the following statement is quoted from the 1946 discussion (1):

"For high-temperature steam turbines, for long service, we have learned that the single-piece rotor forging is best. Thought naturally moves in that direction for gas turbines where even higher temperatures are involved. However, it would appear that our knowledge and ability to handle larger masses of these heat-resisting alloys has not reached the stage where large reliable forgings are possible, and we must rely for a while on disks and assemble them together by welding or other means to meet our development needs. Indeed, it may not be surprising that the disk construction or the composite construction will be the final word in the matter."

A number of articles (4, 5, 6, 7, 8, 9, 10, 11, 12) in the technical press and

before this Society have included illustrations and comments relative to rotor construction, as employed by the four American manufacturers. It is of interest and it is quite important from the standpoint of over-all experience and development that they have seen fit to approach the rotor problem in different ways.

One builder has seen fit to endeavor to procure single-piece rotor forgings for a number of designs. It must be recalled that in steam-turbine practice, as temperatures were increased to present levels, the one-piece rotor has become almost the rule for central station and marine applications, replacing the older built-up designs. Was it not natural, with gas-turbine temperatures even higher, to follow the same approach, rather than go back to the troublesome built-up designs?

The probable difficulties of procuring single-piece rotor forgings were fully appreciated, and they have been experienced. Losses have been high, delays have been great. There have been only a few courageous persons willing to try them, again and again. Some sound acceptable forgings have been produced in the simplest of alloys, 19-9-DL. In the more highly alloyed materials, one company appears to be convinced that the future will have need of this form of construction, and is willing to put its abilities to work on the problem.

Abroad, it is observed that a British steel plant produced a number of one-piece rotor forgings for one of the Swiss builders. Diameters of 20-in., 25-in., and 30-in. were noted. But reports are conflicting, one that they were excellent sound forgings, another that they were found to be quite unsound and could not be used.

Two of the American four companies have built up multi-stage rotors by welding disks and stub shafts together. One of these employed rather shallow welds at first, fashioned somewhat after an older European practice on steam-turbine rotor construction. Cracking of these welds was experienced. There has followed a long period of welding development, and latest reports are that the difficulties have at last been overcome. Gas-turbine operating experience has been seriously delayed through this experience. The story of the successful solution to this problem will be of interest to all.

The other of these two builders employed a somewhat deeper welding groove, similar to that which he had so successfully employed in steam-turbine practice years before. It has been reported that while these practices were quite successful with one high-temperature alloy, cracking was experienced with another of the more highly alloyed types.

The fourth builder has used a welding approach, but of different nature. He has borrowed the composite wheel from its very successful performance in jet-engine and propjet units. The construction is covered in U.S. Patent 2,432,315. The hub or center is made of a ferritic nickel-chromium-molybdenum-vanadium steel, to which is welded a rim forging of the Timken alloy, or other suitable heat-resisting steel. Blade or bucket seating is in the rim portion. The ferritic steel center must of course be cooled to keep its temperature below 1000 F, the lower the better presumably. So far as is known to the author, these disks have not been used in more than two-stage turbines, and they have been bolted or welded together. The welding in this case is between ferritic steel. In the welding of the rim to the ferritic steel center, no particular trouble has been reported, and none would be anticipated. It is generally experienced that welds between ferritic and austenitic members give little or no trouble in welding. Offhand, there appears to be no good reason why multistage rotors of any reasonable number of stages could not be constructed in this manner, but the problem of cooling all of the disks would no doubt introduce some problems.

There are many arguments in favor of

the composite wheel approach. Since the ferritic steel of the center is low-alloy steel, the same type of steel regularly used for steam-turbine rotor forgings, it is well established from the standpoint of ready manufacture in almost any size desired. It is low in alloy content, and would not present a critical material problem in time of emergency. It has the background of many years of successful service for high-speed, high-temperature rotating bodies. It will no doubt be superior to any of the high-temperature alloys from the standpoint of thermal shock.

On the other side, we must await the experience of time as to what metallurgical changes or deterioration may take place in the metal adjacent to the weld. We have seen and heard of objectionable carbide segregation adjacent to the weld, and lowered ductility as well. But even these may have little or no effect on the usefulness of the parts.

There is another approach, that is, the mechanical fastening together of disks to form the desired multistage rotor. We know from our jet-engine experiences that metallurgical knowledge can now produce excellent disks up to 30 in. or so in diameter. If there are but two or three disks, there are various methods of bolting them together. Or if there are many disks, the central bolt method (U. S. Patents 2,458,148 and 2,458,149) may be useful. In either case, disks may be doweled together, or each disk may have projecting flanges having face splines engaging with similar splines on the adjoining disk. It remains to be seen, however, if such mechanically jointed disk construction can remain useful for long times of high-temperature operation.

While discussing the rotor situation, it is well for us to remember that, as a rule, the high-temperature alloys are possessed of low thermal conductivity, and high expansion characteristics and they are probably notch sensitive, making it very necessary to consider the importance of ductility at high temperatures, and to avoid such high stress concentration as would occur at notches, sharp corners, etc.

BLADING OR BUCKETS

There are, in general, three methods of producing turbine blades for gas turbines:

(a) By machining from rolled and heat-treated bars or special shapes.

(b) By drop-forging and machining as required.

(c) By precision-casting methods.

Method (a) offers the simplest metallurgical control, it is the cheapest method, and the most reliable production method. Operators can be readily trained to perform standardized operations. The method is wasteful of critical materials. In its simplest form, it may result in compromising a desired shape of the blade. Some of the better materials do not machine any too readily.

Method (b) offers reasonable freedom to the designer as to shape. Costs are apt to be high by reason of die upkeep and life. Depending on the shape, waste may be high. As pointed out before (1), materials that forge readily are not apt to be good materials for high-temperature service. Better materials from the service-temperature standpoint may be difficult to forge, if not impossible.

Forging practices differ. Some endeavor to practically finish forge the port of the blade to size, and machine only the root portion. Others do not try to forge to size, but employ the forging operation to improve the structure, to conserve metal (over the 100 percent machining method), but they still do machine all over. Any attempts to finish forge thin trailing edges too close to size may result in damage to that edge.

Precision-casting methods offer a means of avoiding many of the foregoing objectionable features. One can cast that

which cannot be forged or machined. One can readily appreciate that temperatures may be reached where only cast materials may be used.

The casting method should be the most economical approach. But with production yields of but 35 percent to 65 percent of the blades cast, there is much room for improvement along these lines.

Cast blades are characterized by wide variations in grain size, and by rather wide variations in high-temperature physical properties. Better metallurgical control is in the making, but results in actual practice are slow in being realized. We do not as yet know how serious is this matter of grain-size variation.

Such extreme statements have been made by some that they would prefer the poorest blade forging possible, in preference to the best precision-cast blade possible. In the aviation field, we must recognize that the operating experiences with cast blades are much more extensive than with forged or machined blades, and one can hardly place cast blades in second position.

Of course, proper design and metallurgical control must be used for either, in a degree necessary to the design and material and process being employed. It is feared that poor cast blades, or poorly designed cast blades, have often been used to compare with the best forged blades.

The question of cast versus forged gas-turbine blades for long-life turbines will not be settled in the immediate future. It is believed that the long-time feature alone will settle the issue, and decree which is best. And since the casting method will steadily improve in the meantime, a really conclusive decision may take even a longer time.

The question of shrouding of rotating blades in long-life gas turbines has been met in some designs. Induction heating of the tangs followed by hand or machine riveting, has been successfully carried out by at least two of the builders. To maintain desired properties in the tangs after such operation is an important consideration.

Corrosion and fouling of gas-turbine blades in long-life turbines are much before us. The time factor is so great as compared with operating experiences in the jet-engine field, and there has been so little real operating experience as yet with the larger gas turbines in this country, excepting under closely controlled laboratory conditions, that we must await experience itself. Lower-grade fuels than those used in aviation, may introduce corrosion problems entirely different than the minor corrosion so far experienced.

Hollow blades, it is believed, merit our more serious consideration. They would help in saving critical material. They would permit of cooling. They would result in lower stresses on the blade fastenings. This last may be more important as temperatures go up.

ALLOY-DEVELOPMENT

The accelerated research of the war years, and the years immediately following, developed a host of new alloys for jet engines, rockets, etc. It must be recognized that few of these alloys have found their way into actual application in engines. To many metallurgists, this has been most discouraging, especially when so many engines were to be built. The long-life units so far built have largely used the same materials as the jet engines, and there has been no opportunity to try out the various other materials there.

We have rather complete short-time data from the laboratory on many of the alloys; on others our data are rather sketchy.

In the long-life gas turbines, although we use certain of the materials, we do not know enough about them to predict what they will be like after years of service. The setting up of test programs on the alloys now being used, and the more

promising of those not yet applied, be they old or new, so that test data may be accumulated and studied, would appear to be a matter of first importance.

In high-temperature alloy development, first impressions of the problem are often apt to send us too far afield. It is a healthy note that some jet-engine builders are stopping and looking back now, to see if there may not be less-rich alloys of ferritic steels that may be employed for some parts, that may be used in-between our older fields of materials and the 1200 F field of our newer alloys.

So far as the 1200/1500 F level is concerned, it would appear that the various alloy fields have been fairly well explored. Improvements in this temperature range are more apt to be made by studying the structure, the influence of heat-treatment and of hot-and cold-working, such as proposed by Franks (13) and Freeman and his coworkers (14), than by further alloy variations and additions. When one considers that Freeman found it possible to vary the time for rupture under 40,000 psi from 100 hr to an estimated 600,000 hr for the same N-155 bar stock with different treatments, the importance of our knowing our present alloys better is apparent. When one considers the spread in physical properties that can be secured in a single master heat of alloy for precision-cast blades, again it should be realized that we have much room for improvement in what we already have.

Much time and effort and money have been expended to develop alloys that might have worthwhile load-carrying ability at higher temperature, such as 1600/1750 F. Many alloy fields have been explored. Iron, nickel, cobalt-base alloys, with roughly up to 20 percent or more of chromium, and with additions up to 7 percent of molybdenum, to 6 percent of tungsten, to 4 percent of columbium have been tried. All sorts of combinations of iron, nickel, chromium, cobalt, tungsten, molybdenum and titanium have been covered. Some few rays of hope still exist. But there appears to be a growing conviction that we are just about through. Of course the following are still to be fully explored: Chromium-base alloys; titanium-base alloys; molybdenum-base alloys; and tungsten-base alloys.

One of the war-time investigations developed a chromium-base alloy. This alloy has been worked on very diligently by one of our best alloy-development groups, constantly since the close of the war. It has excellent properties, but as yet its manufacture into useful articles has not been realized. The excellent properties have been verified by a third laboratory, and attempts to vacuum-cast blades of it are still ahead.

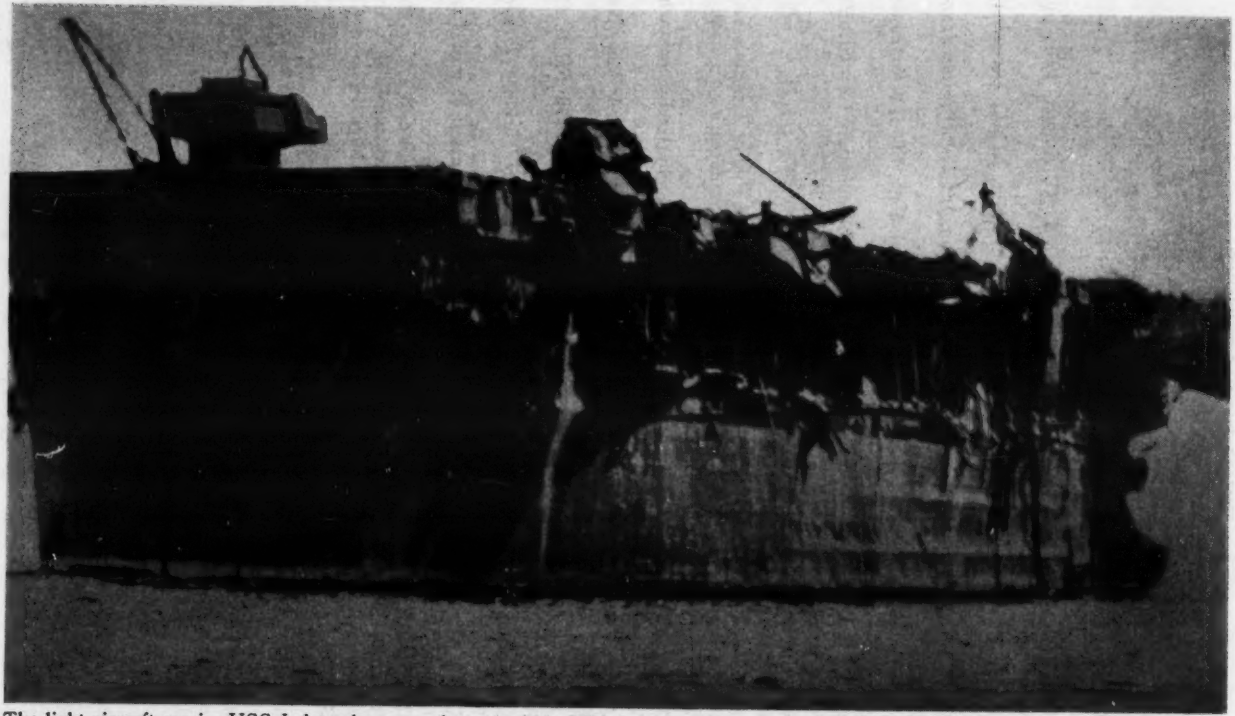
There are some who feel that titanium in fairly large amounts may yet have great value in the high-temperature alloys. Others do not share this view. Further work will clarify this issue in the near future.

Molybdenum and molybdenum-base alloys will receive much attention in the immediate future. But successful application will require the perfection of some means for coating the parts with an impervious protecting surface, to avoid oxidation of the molybdenum.

It is worthy of note that at least three independent development groups have under improvement at the present time, alloys containing increasing amounts of tungsten, and there is some feeling that these may be superior to any of our existing 1500 F alloys.

Bibliography

1. "Metallurgical Considerations of Gas Turbines," by N. L. Mochel, Trans. ASME, vol. 69, 1947, pp. 561-568.
2. "First Worldwide Gas-Turbine Survey," *Power*, vol. 93, August, 1949, pp. 95-97.
3. "The Electric Ingot Process," by R. K. Hopkins, Preprint, AIME, December, 1948.
4. "Welded Gas Turbine Rotors," by J. F. Cunningham, Jr., *The Welding Journal*, vol. 25, March, 1946, pp. 237-241.
5. "A Compact Locomotive-Type Gas Turbine," by T. J. Putz, *The Westinghouse Engineer*, vol. 7, March, 1947, pp. 35-39.
6. "Design and Operation of Some Experimental High-Temperature Gas-Turbine Units," by A. D. Hughes, Trans. ASME, vol. 69, 1947, pp. 549-559.
7. "Current Design Practices for Gas-Turbine Power Elements," by H. D. Emmert, Paper No. 48—A-69, ASME, December, 1948.
8. "A Design of Gas Turbine Suitable for Peak Load and End of Transmission-Line Operations," by W. B. Tucker, Allis-Chalmers Manufacturing Company, February, 1949.
9. "Mechanical Investigation of Gas-Turbine Components," by Carl Schabtach, Paper No. 48—A-47, ASME, December, 1948.
10. "A 5000-Kw Gas Turbine for Power Generation," by Alan Howard, Paper No. 48—A-83, ASME, December, 1948.
11. "Test of a 4800-Hp Gas-Turbine Power Plant," by Alan Howard and B. O. Buckland, Paper No. 48—A-98, ASME, December, 1948.
12. "Gas-Turbine Progress Report—Commercial American Gas Turbine," *Power*, vol. 93, April, 1949, pp. 114-117, 170, and 172.
13. "On the Structure of the High-Temperature Metals," by Russell Franks, Preprint, AISI, May, 1948.
14. "The Influence of Conditions of Heat-Treatment and Hot-Cold Work on the Properties of Low-Carbon N-155 Alloy at Room Temperature and 1200 F," by J. W. Freeman, E. E. Reynolds, D. N. Frey, and A. E. White, 1949, No. 21, Preprint, ASTM, June, 1949.



The light aircraft carrier USS *Independence* was located within 2,600 feet of surface zero at the Bikini air explosion test. The flight deck was broken in several places and the four stacks were demolished. Fire broke out in the hangar deck, adding to the destruction.

CAN SHIPPING SURVIVE AN ATOMIC WAR?

ACKNOWLEDGMENT

The Maritime Reporter for August 15, 1950 contained this article of current interest. The title is self-explanatory.

With the opening of this, the sixth year of the atomic era, high secrecy still surrounds developments in many phases of the atomic energy program, such as the application of atomic energy to ship propulsion. For the first time, however, information has been made available by the Atomic Energy Commission concerning the precise extent that ships are damaged by atomic explosions.

While dealing for the most part with the destruction of military ships, this information is important to the shipping industry because it gives a realistic picture of what may be expected to occur if American shipping is subjected to an atomic attack. It also provides a guide to a limited number of practical protective and remedial steps which can be taken.

Maritime Reporter here presents material which has been selected from "The Effects of Atomic Weapons," just released by the Atomic Energy Commission, and condensed to give a concise picture of the impact of atomic explosions on ships.

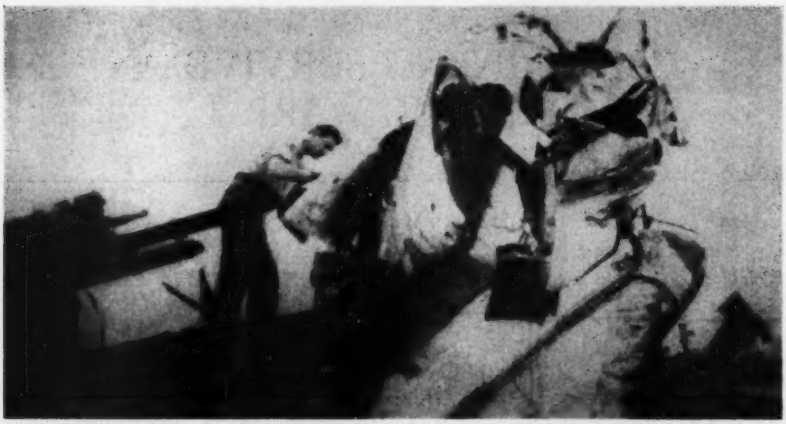
The data disclosed on these pages are based on observations of the atomic bombing of military ships in Bikini lagoon in 1946. The use of more powerful bombs which may have been developed will increase in intensity and magnitude the effects reported here.

While in its blast effect, an atomic explosion is roughly analogous to that of enormous quantities of conventional high explosives, such as TNT, there are radical differences. Intense heat, penetrating radiation and residual radioactivity are unique to atomic weapons.

A temperature of more than a million degrees Centigrade is generated at the center of an atomic blast and would cause severe damage independent of the other effects. Although such a temperature is capable of starting fires up to 10,000 feet, it is not as serious a problem for ships as for land installations. This appears to follow logically because, on a comparative basis, less fire fighting equipment is available for the widespread land fires started and because such equipment is less apt to reach the fires, due to general destruction of the area.

The Bikini tests involved the observation of two atomic explosions, one under water and one in the air above water. The underwater burst, made well below the surface of the 200-foot deep lagoon, caused the water to be thrown up as a hollow cylinder probably some 8000 feet high and with a diameter of about 2000 feet. It is estimated that the maximum thickness of the cylinder walls was about 300 feet and that approximately a million tons of water rose in the cylinder, or plume. The shock wave in air produced by a shallow underwater explosion is equivalent to 4000 tons of TNT.

The flight aircraft carrier USS *Independence* was located within 2,600 feet of surface zero at the Bikini air explosion test. The flight deck was broken in several places and the four stacks were demolished. Fire broke out in the hangar deck, adding to the destruction.



An observer inspects the damage sustained by a navy seaplane on the USS *Nevada* within 2,000 feet of surface zero.

BLAST DAMAGE FROM UNDERWATER EXPLOSION

Evidence indicates that in the underwater explosion, the major cause of damage to the ships in the lagoon was the shock wave transmitted through the water. In general, the nature and extent of the damage to a surface vessel will vary with the distance from the explosion, the ship type, its orientation with respect to the position of the explosion and, strangely enough, whether it is operating or riding at anchor.

It is expected that the lethal or sinking range of all types of surface vessels will be very much the same and will be in the neighborhood of 1200 to 1800 feet from an underwater explosion of the type of atomic bomb considered here. Some ships will probably be sunk out to 2700 feet, but others in this range will suffer considerable structural damage. Submerged submarines will probably be lost out to 2700 feet from the explosion.

Serious loss of efficiency is to be anticipated within a radius of 3600 feet from the blast. Ships must be able to withstand a pressure of over 500 pounds per square inch, the peak pressure of the underwater shock wave at this distance.

The principal types of damage experienced will be weakening of the ship girder, damage to fittings and equipment essential to water-tightness and damage to machinery, electrical and similar equipment, foundations and piping. In addition to the external surface damage, severe shock effects will be transmitted through the hull to interior structure and equipment. Heavy equipment will receive more damage than light equipment.

Boilers and main propulsive machinery will suffer heavy damage out to 2250 feet, moderate damage to 2700 feet and light damage to 3300 feet from the explosion. Auxiliary machinery associated with the propulsive equipment will not suffer as severely, and vessels underway may be expected to suffer somewhat more severe machinery damage than vessels at anchor. For practical purposes, 3000 feet may be taken as the expected radius of immobilization.

The submarine USS *Skate* severely damaged and highly radioactive after the air-above-water explosion at Bikini

In spite of the very high peak pressures which, as seen above, are extremely damaging to ships and possibly also to piers and breakwaters, it is believed that other harbor and shore installations would not be seriously affected by the shock wave transmitted through the water. Of course, vessels sunk at or near piers, or thrown against them, would decrease the effectiveness of the harbor. However, the shock wave in air produced by a shallow underwater explosion half a mile off shore would seriously damage harbor facilities and structures near the water.

Damage can also be expected from the large waves produced. In moderately deep water (at Bikini), the waves formed measured about 20 feet from crest to trough about one mile from the blast and at two miles, the wave height still reached a maximum of 10 feet.

An atomic explosion taking place in deep water and about 1000 feet below the surface, would cause severe damage to merchant-type hulls and light naval craft up to about 3000 feet. Heavy multi-bottom craft would probably survive as close as 2000 feet from the blast. Shock damage to machinery resulting in im-

mobilization may extend out to 4500 feet. General types of damage will approximate those following a shallow burst.

BLAST DAMAGE FROM EXPLOSION IN AIR

In the case of an air burst over water, the destruction would be due almost entirely to the shock wave in the air. Here vessels of all types will suffer serious damage or sinking if they are within 2500 to 3000 feet (horizontal distance) from the explosion. Moderate damage will be experienced out to 4500 feet and minor damage may be expected to occur within a radius of 6000 feet.

Exposed structures, such as masts, spars, and radar antennae, will be subjected to severe damage up to 3000 or 3500 feet as will light vehicles, airplanes, light structures and electronic equipment on the ships.

Ship machinery would probably remain intact within the range in which the ship survives. The main exception is blast damage to boilers and uptakes, and this will account for most cases of immobilization. Boilers may be expected to suffer heavy damage out to 2700 feet, moderate damage to 4000 feet and light damage to nearly 5000 feet.

In the event of an atomic war, perhaps the best and only prevention from both underwater and air blasts is to practice ship dispersion so that an adequate target for an atomic bomb is never presented. Once an attack appears possible, blast damage can be minimized by closing all exterior openings. Shock-mounted equipment also stands a better chance of survival.

The stern deck of the USS *Nevada*, within 2,000 feet of surface zero, damaged by the air explosion at Bikini.

Japanese cruiser *Sakawa* was so severely damaged above and below the water line that she sank on the following day.

RADIOACTIVITY

Residual radioactivity resulting from the explosion of an atomic bomb may render an area incapable of supporting any life, plant or animal, for many years. In the Bikini tests, the two areas of consequence to shipping which were subject to radiation effects were the targets, or ships, and the surrounding water.

An underwater burst forms a contaminated cloud of mist 10 to 12 seconds after the explosion. This cloud, which will add markedly to the radioactivity deposited on ships, then moves rapidly outward and may cause serious damage for a distance of several miles, especially in a downwind direction. The fact that the cloud is most hazardous for

Preliminary decontamination of the USS *New York* after the underwater test; decks are being washed with sea water.

a period of short duration, indicates the advantage of protection during the first 3 or 4 minutes immediately following the explosion. At Bikini, contamination of the interiors of ships, due to the base surge, was minimized by closing down the hatches and stopping the ventilating systems. It may be noted here that instruments are available for the detection of contamination.

Contamination of water is not as high as might be feared except close to the explosion center and within a short time of the burst. Thus while passage across contaminated water would not be a great hazard, it is not a good idea for a ship to remain in such an area for any length of time soon after the explosion. In any case it is necessary that condensers and evaporators be closed down while a ship is in contaminated water.

There are three methods whereby radioactive contamination may be minimized: dispose of material by deep burial in ground or at sea; keep material at a distance for a sufficient time to permit radioactivity to decay to a reasonably safe level; and where feasible, attempt removal of contamination.

In general, the problem of decontamination is, to a considerable degree, a problem of removing enough of the surface material to reduce activity to the extent that it is no longer a hazard. Where this is possible, either through wet sandblasting or other methods, both chemical and physical, and where blast damage is not irrepairable, ships can again be made fit for operation.

Once again, bear in mind that the use of more powerful bombs which may have been developed will increase in intensity and magnitude the effects reported here.

BOILER WATER TREATMENT

ACKNOWLEDGMENT

This article by MR. H. HILLIER, O.B.E., appeared in the Transactions of the Institute of Marine Engineers for January, 1950. The complete article was entitled "Boiler Corrosion and Boiler Feed Water Treatment." The first half of the article on boiler corrosion is not repeated in view of its similarity to the article "Boiler Deterioration," reprinted in the previous issue of the JOURNAL for May, 1950.

The treatment of boiler feed water should have the following objects:—

(a) Prevention of scale formation in the feed and boiler systems.
(b) Control of the sludge formation and the total dissolved solids in the boiler.
(c) Avoidance of carry over with the boiler steam.
(d) Prevention of corrosion in the feed and boiler systems.
(e) Neutralization of any residual corrosive gases which may be left in the feed water.

It is extremely desirable that distilled water should be used in high-pressure boilers but there are many plants in which make-up feed is taken from a town supply or other convenient source. Water from such sources often contains undesirable solids from the earth's crust such as calcium and magnesium salts which are hardness producing substances. The earth's crust, the sea and the atmosphere are largely composed of eleven elements: oxygen, hydrogen, silicon, aluminum, iron, calcium, magnesium, sodium, potassium, carbon and chlorine. In marine plants, ingress of sea water into the feed systems may occur with consequent undesirable solid matter. A typical sample of sea water is as follows (3):—

	p.p.m.
Calcium bicarbonate, $Ca(HCO_3)_2$	180
Calcium sulphate, $CaSO_4$	1,220
Magnesium sulphate, $MgSO_4$	1,960
Magnesium chloride, $MgCl_2$	3,300
Sodium chloride, NaCl	25,620
	33,280

("p.p.m." is "parts per million" by weight, compared with pure water and is the weight of each substance in pounds per million pounds of pure water.)

The total dissolved solids in sea water are about 32,000 parts per million, of which 25,600 are sodium chloride, the remainder being salts of calcium and magnesium. It is very important therefore, to prevent the ingress of sea water into boilers, and on board ship it is now the almost invariable practice to use double distillation for make-up feed water to ensure the least possible sea contamination.

Where necessary, chosen solids are added to feed water to counteract any scale forming substances which may be in the water, and to increase its hydroxyl ion concentration to prevent corrosion.

Every possible step should be taken to reduce the presence of contaminating solids to a minimum so that the required amounts of corrective additions are also reduced to a minimum.

Metallic Elements

TABLE 4

Metal	Symbol	Valence or combining ratio	Relative atomic weight	Equivalent weight	Normal complement of electrons	Arrangement of electrons in shells	Ion
Calcium	Ca	2	40	20	20	2.8.8.2	Ca^{++}
Magnesium ...	Mg	2	24·3	12·15	12	2.8.2	Mg^{++}
Sodium	Na	1	23	23	11	2.8.1	Na^{+}
Potassium ...	K	1	39·1	39·1	19	2.8.8.1	K^{+}
Aluminium ...	Al	3	27	9	13	2.8.3	Al^{+++}
Iron	Fe	2	55·8	27·9	26	2.8.14.2	Fe^{++}
		3	55·8	18·6	26	2.8.14.2	Fe^{+++}
Barium	Ba	2	137·4	68·7	56	2.8.18.18.8.2	Ba^{++}
Hydrogen ...	H	1	1	1	1	1	H^{+}

SUBSTANCES AND THEIR MOLECULAR GROUPINGS

To understand the corrective actions it is necessary to consider the principal molecular groupings which take place and those which are desirable. The main solids or metals which may be present in the water are shown in Table 4.

Hydrogen has been included in the list of metals because in many respects it behaves in the same way as a metallic substance.

When the above metals combine with hydroxide, OH, they form bases but when they combine with an acid radical they form salts. The calcium and magnesium salts are the chief cause of trouble in boilers.

Valence is the measure of the combining ratio of a substance or compound taking hydrogen as the datum of one. The number of atoms of hydrogen displaced by or combined with one atom of a given element is the measure of the valence of that element. Elements or compounds combine in the ratio of one to one for the same valence but inversely as their valence when their valences differ.

The valency is determined by the arrangement of the electrons in the outermost shell of an element, the shell tending to give up or acquire electrons in order to reach the most stable arrangement of electrons.

The relative atomic weight is the weight of a given number of atoms of a substance relative to the weight of the same number of atoms of hydrogen. The atomic weights given are to the nearest convenient round figures.

The weight of 602,000,000,000,000,000,000,000, i.e., 6.02×10^{23} atoms of hydrogen is 1.008 grams while the weight of the same number of calcium atoms is 40 grams. 1 lb. of hydrogen, therefore, contains the same number of atoms as 40 lb. of calcium or 23 lb. of sodium.

The weight of an ion can be taken as the weight of the atom because a proton or neutron weighs 1830 times the weight of an electron.

A chemical equation gives the ratios in which the atoms and molecules stated take part in the reaction given by the equation. The same ratios can be expressed in the respective atomic and molecular weights. If the weight of any substance taking part in the reaction covered by the equation is known, then the weights of the other substances taking part in the reaction are proportional to the respective atomic and molecular weights.

The equivalent weight is the atomic weight or molecular weight divided by the valence and is a convenient relation for enabling the weight of a substance to be expressed in terms of weight of another substance.

Other non-metallic elements which enter into this consideration are given below in Table 5.

Non-Metallic Elements

TABLE 5

Element	Symbol	Valence or combining ratio	Relative atomic weight	Equivalent weight	Normal complement of electrons	Arrangement of electrons in shells	Ion
Oxygen	O	2	16	8	8	2.6	O^{--}
Nitrogen ...	N	Variable (3)	14	4·7	7	2.5	N^{---}
Sulphur	S	Variable (2)	32·1	16	16	2.8.6	S^{--}
Chlorine	Cl	1	35·5	35·5	17	2.8.7	Cl^{-}
Phosphorus ...	P	3	31	10·3	15	2.8.5	P^{---}
Carbon	C	Variable (4)	12	3	6	2.4	$C^{\pm 4}$
Silicon	Si	Variable (4)	28·1	7	14	2.8.4	$Si^{\pm 4}$

The valence figure given in brackets is the common valence for the element.

Water

Water is the liquid mainly concerned with here and pure water is as follows:—

TABLE 6

Compound	Symbol	Combining ratio	Relative atomic weight	Equivalent weight
Water	H_2O	1	18	18

Acid Radicals

An acid radical is, in general, a molecular grouping which usually moves as a unit in any regrouping and the principal acid radicals to be considered are given in Table 7.

It will be seen that the radicals are largely oxygen compounds. In their ionic form they have a very stable electronic configuration, as will be discussed later.

The molecular weight is the combined atomic weights of the atoms in the molecule of the given compound. For example the atomic weights of sulphur, S, and oxygen, O, are 32.1 and 16 respectively, so the molecular weight of sulphite, SO_3, is 32.1 plus $(3 \times 16) = 80.1$.

Acids

The above acid radicals when they combine with hydrogen, H, form an acid, as shown in Table 8.

Carbonic acid H_2CO_3, when heated, breaks up into H_2O and CO_2.

TABLE 7

Radical	Symbol	Valence or combining ratio	Relative molecular weight	Equivalent weight	Ion
Bicarbonate	HCO_3	1	61	61	$(HCO_3)^{-}$
Carbonate	CO_3	2	60	30	$(CO_3)^{--}$
Sulphate	SO_4	2	96·1	48	$(SO_4)^{--}$
Sulphite	SO_3	2	80·1	40	$(SO_3)^{--}$
Phosphate	PO_4	3	95	31·7	$(PO_4)^{---}$
Nitrate	NO_3	1	62	62	$(NO_3)^{-}$
Hydroxide	OH	1	17	17	$(OH)^{-}$
Chloride	Cl	1	35·5	35·5	Cl^{-}

TABLE 8

Acid	Symbol	Combining ratio	Relative molecular weight	Equivalent weight
Carbonic acid	H_2CO_3	2	62	31
Sulphuric acid ...	H_2SO_4	2	98·1	49
Sulphurous acid ...	H_2SO_3	2	82·1	41
Phosphoric acid ...	H_3PO_4	3	98	32·7
Hydrochloric acid ...	HCl	1	36·5	36·5

Calcium Compounds

The compounds of the acid radicals with calcium and magnesium are the chief factors in scale formation, and are as given in Tables 9-12:—

TABLE 9

Compound	Symbol	Combining ratio	Relative molecular weight	Equivalent weight
Calcium bicarbonate	$Ca(HCO_3)_2$	2	162	81
Calcium carbonate	$CaCO_3$	2	100	50
Calcium hydroxide (Slaked Lime)	$Ca(OH)_2$	2	74	37

The above are known as alkaline hardnesses (often called carbonate or temporary hardnesses). The following are all known as non-alkaline hardnesses (often called non-carbonate or permanent hardnesses).

TABLE 10

Compound	Symbol	Combining ratio	Relative molecular weight	Equivalent weight
Calcium sulphate	$CaSO_4$	2	136·1	68
Calcium silicate	$CaSiO_3$	2	116·1	58
Calcium nitrate	$Ca(NO_3)_2$	2	164	82
Calcium chloride	$CaCl_2$	2	111	55·5
Tricalcium phosphate	$Ca_3(PO_4)_2$	6	310	51·7

$Ca(HCO_3)_2$ is decomposed by heating when carbon dioxide CO_2 is driven off, and calcium carbonate $CaCO_3$ is precipitated, i.e., $Ca(HCO_3)_2 \rightarrow \underline{CaCO_3} + H_2O + \overline{CO_2}$.

(In a chemical formula, the total number of atoms of each particular element must be the same on each side of the equation. In the same way the total of the electric charges must balance out on each side of the equation.) A line under a symbol indicates a precipitate or solid, e.g., $\underline{CaCO_3}$. A line above a symbol indicates a gas, e.g., $\overline{CO_2}$.

$CaCO_3$ is largely insoluble and forms a soft sludge or soft scale. $CaSO_4$ is the chief constituent of hard scale.

Calcium silicate may be a constituent of the thin hard and non-conducting silicate scales which are troublesome to remove and may cause overheating.

Calcium hydroxide, commonly called slaked lime, is frequently used for boiler water conditioning for the removal of temporary hardnesses as follows:—

$$Ca(OH)_2 + Ca(HCO_3)_2 \rightarrow \underline{2CaCO_3} + 2H_2O$$

$$2Ca(OH_2 + Mg(HCO_3)_2 \rightarrow \underline{2CaCO_3} + \underline{Mg(OH)_2} + 2H_2O.$$

Slaked lime also reacts with permanent magnesium hardnesses but produces an equivalent amount of temporary calcium hardness. This is known as the lime treatment and is frequently combined with the soda treatment mentioned later.

Tricalcium phosphate is a soft sludge which is formed in phosphate conditioning which will be described later.

Magnesium Compounds

TABLE 11

Compound	Symbol	Combining ratio	Relative molecular weight	Equivalent weight
Magnesium bicarbonate	$Mg(HCO_3)_2$	2	146·3	73·1
Magnesium carbonate	$MgCO_3$	2	84·3	42·1
Magnesium hydroxide	$Mg(OH)_2$	2	58·3	29·1

The above are known as alkaline hardnesses (often called carbonate or temporary hardnesses). The following are all known as non-alkaline hardnesses (often called non-carbonate or permanent hardnesses).

TABLE 12

Compound	Symbol	Combining ratio	Relative molecular weight	Equivalent weight
Magnesium sulphate	$MgSO_4$	2	120·4	60·2
Magnesium silicate	Mg_2SiO_4	4	140·7	35·2
Magnesium nitrate	$Mg(NO_3)_2$	2	148·3	74·1
Magnesium chloride	$MgCl_2$	2	95·3	47·6

$Mg(HCO_3)_2$ is decomposed by heating when CO_2 is driven off and magnesium carbonate $MgCO_3$ is formed, i.e., $Mg(HCO_3)_2 \rightarrow MgCO_3 + H_2O + \overline{CO_2}$.

$MgCO_3$ is relatively insoluble but it is decomposed into magnesium hydroxide and carbon dioxide as follows:—

$$MgCO_3 + H_2O \rightarrow Mg(OH)_2 + \overline{CO_2}.$$

$MgSO_4$ and $MgCl_2$ are soluble in boiler conditions. Magnesium chloride

is decomposed to some extent under boiler conditions into magnesium hydroxide and hydrochloric acid as follows:—

$$MgCl_2 + 2H_2O \rightarrow \underline{Mg(OH)_2} + 2HCl.$$

Magnesium hydroxide is the commonest magnesium compound found in boiler scale and may form a hard scale but it is usually precipitated as a sludge with phosphate treatment.

Magnesium silicate forms a hard thin scale which is nonconducting, difficult to remove and may give rise to dangerous overheating.

As will be seen from the above, magnesium compounds produce acids which require neutralizing by alkaline additions.

Sodium Compound

$2NaHCO_3$, when heated, breaks down into $Na_2CO_3 + H_2O + \overline{CO_2}$. Na_2CO_3, when subjected to the temperatures in high pressure boilers, breaks down and combines with water H_2O into caustic soda 2NaOH and $\overline{CO_2}$.

Sodium sulphite is used as an oxygen scavenger in the boiler after mechanical de-aeration.

TABLE 13

Compound	Symbol	Combining ratio	Relative molecular weight	Equivalent weight
Sodium bicarbonate	$NaHCO_3$	1	84	84
Sodium carbonate (Soda ash)	Na_2CO_3	2	106	53
Sodium hydroxide	NaOH (Caustic soda)	1	40	40
Sodium sulphate	Na_2SO_4	2	142·1	71
Sodium sulphite	Na_2SO_3	2	126·1	63
Sodium nitrate	$NaNO_3$	1	85	85
Sodium chloride	NaCl	1	58·5	58·5
Sodium aluminate	$Na_2Al_2O_4$	6	164	27·3

A general characteristic of sodium compounds is their high solubility and, because of this, they are non scale forming.

Soda ash and caustic soda are both used for feed and boiler water conditioning because they decompose readily, they increase the alkalinity of the water, and they cause the precipitation of hardness forming substances as sludge. They are satisfactory for use up to boiler pressures of 250 lb. per sq. in., but require careful consideration above that pressure because they may unduly increase the alkalinity in the boiler and the total dissolved solids present.

Sodium aluminate is a coagulant which is used to make a floc that settles easily and can be blown down.

TABLE 14

Compound	Symbol	Combining ratio	Relative molecular weight	Relative combining weight
Monosodium phosphate	NaH_2PO_4	3	120	40
Disodium phosphate	Na_2HPO_4	3	142	47·3
Trisodium phosphate	Na_3PO_4	3	164	54·7
Commercial trisodium phosphate ...	$Na_3PO_4.12H_2O$	3	380	127
Sodium metaphosphate	$NaPO_3$	1	102	102
Sodium hexametaphosphate	$(NaPO_3)6$	6	612	102

Sodium phosphates are widely used for water conditioning, particularly in high-pressure boilers, because they are very soluble and the phosphate radical is entirely stable at the higher operating pressures and combines with calcium and magnesium to form a sludge. The three types of phosphates mainly used in conditioning boiler water are sodium metaphosphate, disodium phosphate, and trisodium phosphate.

If sodium metaphosphate or disodium phosphate is added to boiler water containing caustic alkalinity it is converted into trisodium phosphate in the boiler.

Sodium metaphosphate is highly soluble and in a weak solution has a *p*H value of the order of 7. Disodium phosphate in a 1 percent solution in water has a *p*H value of 9.3 and is therefore more alkaline, while trisodium phosphate in a solution of 1 percent in water, has a pH value of 12.0.

Sodium metaphosphate has an advan-

tage compared to the others in that it can be added to the feed water without causing deposition in the feed piping, but it is the more general practice to use phosphate conditioning direct into the boiler.

The different alkalinities of the phosphates mentioned enable them to be used to control alkalinity in the boiler, particularly when the feed water contains only small amounts of solid matter. Sodium metaphosphate and trisodium phosphate are those generally used when it is desired to control alkalinity by their use.

Phosphate conditioning has another advantage in that it tends to form an iron phosphate film on the boiler surfaces which is a protection against corrosion.

SCALE FORMATION AND OILY DEPOSITS

Scale formation is a complex process which is partly physical and partly chemical. When a bubble of steam is formed on a heating surface, the evaporation of the water into the bubble of steam causes a local concentration of the solids and the super saturation point of the solids may be reached when the precipitation of a ring of crystals occurs at the perimeter of the bubble on the heating surface. If the salts precipitated are highly soluble, when the bubble escapes from the heating surface, the subsequent flow of water across the surface where the bubble was formed causes the salts to re-enter into solution, but in the case of relatively insoluble salts, they may adhere to the heating surface and the repeated formation of circles of crystals builds up a scale formation.

Fig. 25 shows rings of calcium sulphate crystals precipitated (11) on a heating surface when water is evaporated and illustrates the beginning of scale formation. The scale formation thus formed can be augmented by the crystallization of solids in solution on to the solids precipitated by evaporation. The worst offender is calcium sulphate which crystallizes in long crystals which interlace and form a close adherent scale. This is shown in Fig. 26, (11) which shows the cross-sectional and surface appearance of hemihydrate and anhydrite scales produced experimentally under the following conditions:

TABLE 15

Boiler pressure, lb. per sq. in. gauge	Duration of run, hours	Thickness of scale, inch	Crystal form of calcium sulphate in scale	Magnification
25	48	0·056	Hemihydrate	20
150	200	0·0032	Anhydrite	43

The three main substances which are precipitated in this manner are calcium sulphate, calcium silicate, and magnesium silicate. Calcium carbonate and magnesium hydroxide may be incorporated in the matrix of the scale in appreciable amounts. The presence of calcium carbonate in the scale reduces its hardness and the greater the proportion of calcium carbonate in the scale the softer the scale is until it becomes a sludge when the precipitate is formed chiefly of calcium carbonate.

The various other calcium and magnesium salts also play a part in the physico-chemical growth of scale, but the above are the main sources of trouble.

It will be appreciated that the metal of a boiler tube is maintained at a tem-

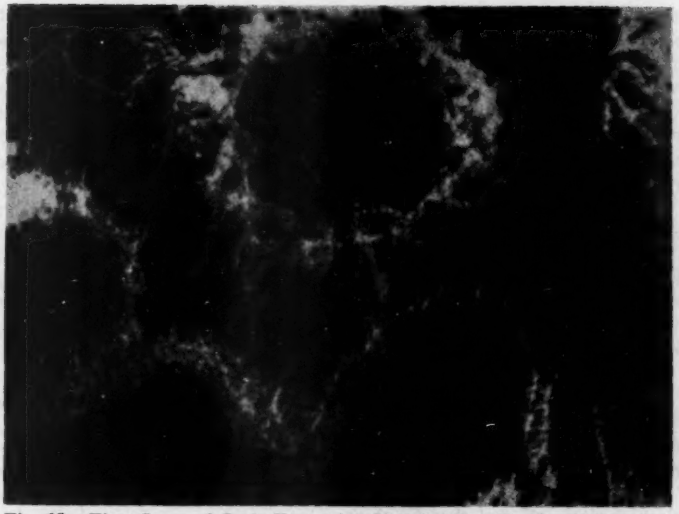


Fig. 25.—First Stage of Scale Formation Showing Precipitation of Rings of Calcium Sulphate Crystals.

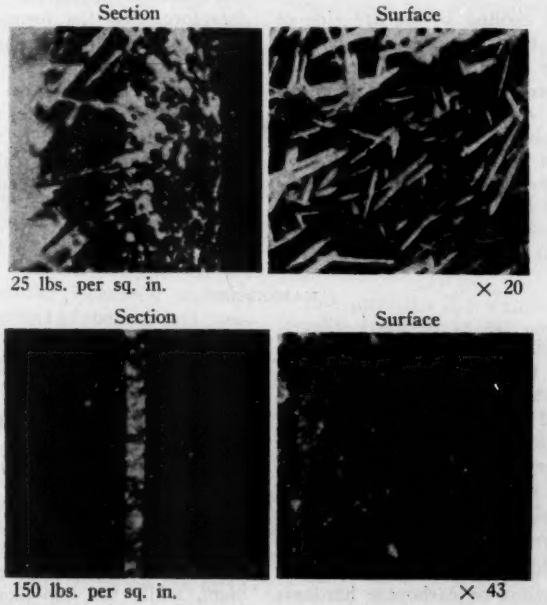


Fig. 26.—Cross-Sectional and Surface Appearance of Hemihydrate and Anhydrite Scales from an Experimental Boiler at Stated Pressures.

perature intermediate between the gas temperature and the boiler water or steam temperature, and that, for safe working, the tube wall temperature must be reasonably close to the boiler water or steam temperature.

Scale formation, even of a thin character, offers a considerable resistance to heat flow and such resistance can be appreciably increased if it is combined with corrosive products or oil. Any coating of oil or scale on the water or steam side of a boiler tube will cause the tube metal temperature to rise because of the greater resistance to heat flow from the metal and such temperature rise may cause more vigorous scaling with cumulative effects resulting in rupture of the tube.

On the gas side, overheating of the tube wall causes the formation of forge scale which peels off and thereby thins the tube wall, thus contributing to the rupturing of the tube.

Defective cooling of the fire side of a tube is liable to cause serious bowing of the tube which may be such as to cause a permanent set every time the boiler goes on load. The repetition of this excessive stress every time the boiler is put into service and shut down is liable to give rise to transverse cracking of the tube wall which will be accelerated if any corrosive action is present. Scale formation may also give rise to "steam" corrosion.

Oil in the boiler water is a serious source of danger. A small amount of oil can be present without causing damage provided the boiler is free from scale forming substances but, if scale is formed, the presence of oil will promote the accumulation of scale and increase its resistance to the necessary flow of heat, thereby accelerating any destructive corrosion or overheating action which may take place.

In some cases, oil may combine with hardness producing substances and rust to form oily balls which may so seriously reduce the flow of water in a tube as to cause overheating of the tube, finally causing rupture. This danger is particularly present when a new boiler goes into service, or after a boiler has been opened up for some time, when rust may have formed inside. It is important, therefore, that the formation of scale should be avoided or minimized as far as it is practicable. To this end, the make-up feed should be as free from solid matter as possible, and any solid matter present shqld be treated chemically to make it non-scaling. All possible steps should, of course, be taken to prevent oil entering a boiler.

HARDNESSES

The calcium and magnesium salts, which are the scale producing solids, are termed the hardness producing substances and a knowledge and measure of the various hardnesses in a water are necessary in considering the conditioning of the water. The hardnesses can be broadly divided into the following categories:—

(a) Total hardness.

(b) Alkaline or carbonate hardness (often called temporary hardness).

(c) Non-alkaline or non-carbonate hardness (often called permanent hardness).

The total hardness is the sum of the calcium and magnesium salts present and is usually expressed in terms of $CaCO_3$.

The alkaline hardness is the sum of all the bicarbonates, carbonates and hydroxides of the calcium and magnesium, while the non-alkaline hardness is the sum of all the remaining salts of calcium and magnesium, such as the

TABLE 16

Degrees	Parts per million as $CaCO_3$
1 British	14·29 = 1 grain per Imperial gallon
1 American	17·16 = 1 grain per U.S. gallon
1 French	10·00
1 German	17·86

chlorides, sulphates, silicates and nitrates.

The bicarbonates are said to be "temporary hardnesses" because they are decomposed by heating or boiling into carbonates and carbon dioxide, while the magnesium carbonate is further changed into magnesium hydroxide and carbon dioxide. The calcium and magnesium salts which do not decompose in this manner are termed permanent hardnesses.

British, American, French and German degrees of hardness vary and Table 16 gives the relation between them in terms of $CaCO_3$.

Water can contain such a variety of solids in different proportions that it is convenient to be able to evaluate the scale producing solids in terms of a single solid or in degrees of hardness. This enables rough comparisons to be made between waters and permits a rough approximation to be made to the corrective treatment required. Modern boiler water treatment, however, is a much more exact science and a detailed analysis of the solid contents of feed water is necessary to enable the correct treatment to be applied, as is discussed later.

Scale formation is due to the precipitation of the hardness forming substances, the worst compounds being as stated previously. Scale can be avoided by conditioning the water so that no calcium sulphate, calcium silicate or magnesium silicate are formed at the evaporating surfaces, and any precipitates formed are sludge forming substances.

In the feed system and economizers, the main requirement to avoid scale formation is that supersaturation of calcium carbonate $CaCO_3$ or magnesium silicate Mg_2SiO_4 shall not occur.

FEED WATER ANALYSIS

When the compounds previously considered are present in solution in water they are in the form of the ions of their elements and radicals. In a chemical analysis, the quantities of the various ions are measured separately and the probable groupings of the ions into compounds are estimated on the basis of the combinations in which they would probably be precipitated from solution if the water is progressively removed. This estimate is based on the assumption that the ions are balanced to form various compounds in their increasing order of solubility as this will be the order in which they will be precipitated.

A water analysis may, therefore, be given in ionic form although the more usual and conventional way is to state the probable combinations. For water treatment purposes, the ionic analysis would be equally convenient since the knowledge required is the actual number of each ion present in the water and both forms of analysis give this information.

The quantities in a water analysis are usually given in grains per gallon or p.p.m. and, for convenience, they are often expressed in terms of a single compound such as $CaCO_3$. The equivalent weights given in the lists of elements, radicals and compounds enable the weight of any given substance to be obtained in terms of another substance by taking the ratio of their equivalent weights:—e.g., if a water contains 30 p.p.m. of magnesium sulphate, this is equivalent to $\frac{30 \times 50}{60.2} = 25$ in terms of $CaCO_3$ where 50 and 60.2

TABLE 17

		p.p.m.	e.p.m.	p.p.m. as $CaCO_3$
Calcium carbonate	$CaCO_3$	197	3·94	197 Alkaline hardness
Calcium sulphate	$CaSO_4$	91	1·34	67 } Non-alkaline
Magnesium sulphate	$MgSO_4$	30	0·50	25·0 } hardness
Sodium nitrate	$NaNO_3$	34	0·40	20·0
Sodium chloride	NaCl	47	0·80	40·0
Silica	SiO_2	3	0·10	5·0
Iron oxide	Fe_2O_3	2	0·07	3·5
Free ammonia		Nil		
Albuminoid ammonia		Nil		
Total solids dried at 105 deg. C.		432		

TABLE 19

		p.p.m.	e.p.m.	p.p.m. as $CaCO_3$
Calcium carbonate	$CaCO_3$	5·6	0·112	5·6 Alkaline hardness
Calcium sulphate	$CaSO_4$	2·4	0·035	1·8 } Non-alkaline
Magnesium sulphate	$MgSO_4$	2·1	0·035	1·8 } hardnesses
Sodium chloride	NaCl	16·4	0·280	14·0
Silica	SiO_2	0·3	0·01	0·5
Iron oxide	Fe_2O_3	0·1	0·004	0·2
Total solids dried at 105 deg. C.		30		

Alkaline hardness 5·6 p.p.m. as $CaCO_3$ or 0·39 degrees.
Non-alkaline hardness 3·6 p.p.m. as $CaCO_3$ or 0·25 degrees.

are the equivalent weights of $CaCO_3$ and $MgSO_4$ respectively.

Table 17 gives a typical analysis of water from a London source.

It will be noted that the quantity of total solids as estimated by drying is greater than the sum of the constituents since many of the salts contain varying amounts of combined water of crystallization which is not completely removed by drying at 105 deg. C.

If the quantities are given in grains per gallon, multiply by 14.29 to obtain p.p.m.

To obtain the e.p.m. divide the p.p.m. by the equivalent weight of the compound. To obtain the p.p.m. as $CaCO_3$ multiply the e.p.m. by 50 which is the equivalent weight of $CaCO_3$.

The only alkaline hardness present in this water is the $CaCO_3$, which is 197 p.p.m. which is $\frac{197}{14.29} = 13.8$ degrees.

The non-alkaline hardness is the summation of the remaining calcium and magnesium salts in p.p.m. as $CaCO_3$ divided by 14.29, i.e.,
$67 + 25 = 92 \div 14.29 = 6.4$ degrees.

The analysis could be equally usefully given in ionic form as follows:—

TABLE 18

		p.p.m.	e.p.m.	p.p.m. as $CaCO_3$
Calcium ions	Ca^{++}	105·6	5·28	264
Magnesium ions	Mg^{++}	6·0	0·50	25
Sodium ions	Na^{+}	27·7	1·20	60
Carbonate ions	CO_3^{--}	118	3·94	197
Sulphate ions	SO_4^{--}	88·2	1·84	92
Nitrate ions	NO_3^{-}	24·8	0·40	20
Chloride ions	Cl^{-}	28·5	0·80	40

For water conditioning, the calcium and magnesium ions require to be removed and their quantities together with the quantity of carbonate ions must be known to enable the required quantities of addition compounds to be estimated. The alkaline hardness is the amount of carbonate ions present, which equals 197 p.p.m., as $CaCO_3$. The non-alkaline hardnesses are the magnesium ions present plus the calcium ions not balanced with the carbonate ions (all expressed in terms of $CaCO_3$), i.e., $264 + 25 - 197 = 92$ p.p.m. as $CaCO_3$. If the carbonate ions are in excess of the calcium ions the balance would be associated with magnesium ions and the hardness arrived at in the same way.

The water given above would be termed a hard water. The analysis in Table 19 is of a Glasgow water which is a soft water.

The above analysis in the ionic form is shown in Table 20.

If the hardnesses are all expressed in terms of $CaCO_3$, simple calculations, as will be seen later, will enable the theoretical weights of the required conditioning compounds to be determined.

TABLE 20

		p.p.m.	e.p.m.	p.p.m. as $CaCO_3$
Calcium ions	Ca^{++}	2·95	0·148	7·4
Magnesium ions	Mg^{++}	0·42	0·035	1·7
Sodium ions	Na^{+}	6·45	0·280	14·0
Carbonate ions	CO_3^{--}	3·36	0·112	5·6
Sulphate ions	SO_4^{--}	3·38	0·070	3·5
Chloride ions	Cl^{-}	9·95	0·280	14·0

SOLUBILITIES

In the boiler, the precipitation of sludge instead of scale is required and in this connection the temperature corresponding to the boiler pressure is an important factor. The temperature gradient in the water rises toward a heating surface but falls towards a cooling surface. As a general rule, therefore, substances whose solubilities increase with temperature, when concentrated beyond the saturation point, deposit as a sludge on heating surfaces but form a scale on cooling surfaces. Conversely, if a substance has a solubility which decreases with increase in temperature, when saturation point is reached, it forms scale on heating surfaces and a sludge on cooling surfaces.

Salts, bases and acids are all soluble in water to a greater or lesser extent but the factors which influence the solubility are complex and, in general, the degree of solubility of an element or compound can be determined only by experiment and is influenced greatly by the presence of other elements or compounds. In a boiler, the various solids are present in a comparatively dilute concentration, so far as the mass of the boiler water is concerned, but in hide outs and where the bubbles are formed at the evaporating surfaces, the concentration of solids reaches the limit of solubility and precipitation occurs. Both states have therefore to be considered.

The electronic configuration of a given compound and the weight of any given aggregation of molecules play a part in precipitation, but there is such a complexity of factors that, for the present, reliance has to be placed on experimental results.

It is interesting, however, to examine some of the factors. In their reactions, the atoms of elements tend to achieve the electronic arrangement of the nearest inert gas. An inert gas has the maximum possible number of electrons in each orbit and, after the first orbit, which has a maximum of two electrons, the outermost orbit always contains eight electrons. Such an arrangement is extremely stable and has practically no tendency to undergo a change. The electronic arrangements of the various inert gases are shown in Fig. 27.

The formation of compounds is due to the tendency of each atom to acquire a stable electronic arrangement with two electrons in the first orbit or eight electrons in the outermost orbit, which is the maximum the outermost orbit can contain. If an atom has three orbits only, the third orbit can contain up to eight electrons but if additional orbits are present, the third orbit can contain up to eighteen electrons, but the outermost orbit in all cases, from the second orbit to the sixth, can contain eight electrons only as a maximum.

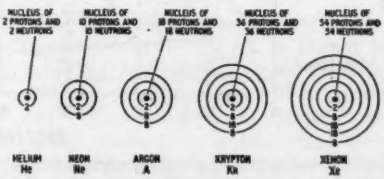

NUCLEUS OF 2 PROTONS AND 2 NEUTRONS
NUCLEUS OF 10 PROTONS AND 10 NEUTRONS
NUCLEUS OF 18 PROTONS AND 18 NEUTRONS
NUCLEUS OF 36 PROTONS AND 36 NEUTRONS
NUCLEUS OF 54 PROTONS AND 54 NEUTRONS
HELIUM He
NEON Ne
ARGON A
KRYPTON Kr
XENON Xe

FIG. 27—*Diagram of the atoms of the inert gases showing the electronic arrangements*

The formation of compounds, therefore, tends to an arrangement in which each atom has the nearest approach possible to two electrons in a single orbit or, with multiple orbits, to eight electrons in its outermost orbit, and this may be obtained by losing or gaining an electron or electrons, as in ionization followed by ionic binding, or by sharing electrons as in what is termed co-valent binding, or by a combination of both forms.

The energy necessary to remove one electron from a particular atom is less than that required to remove two and so on, and these respective energies vary between the atoms depending upon how closely their electronic arrangement approaches the nearest stable configuration. Fig. 28 shows the energy necessary to remove electrons from the atoms of some of the elements concerned in this subject. Practically all chemical compounds contain an even total number of electrons and they tend to achieve the most stable arrangement. Ions, molecules or compounds in their movements in a gas or a liquid are continually coming into contact with each other, and when they approach one another sufficiently closely for interpenetration of their electronic shells to take place, the attractive or repulsive forces which exist or are set up may cause binding or dissociation depending upon the respective electronic configurations, and the gain, loss or sharing of electrons which takes place.

An ion may have a very stable electronic configuration but it will have a resultant electric charge and when two ions with opposite electric charges come into contact they are held together by the balancing of their electric charges

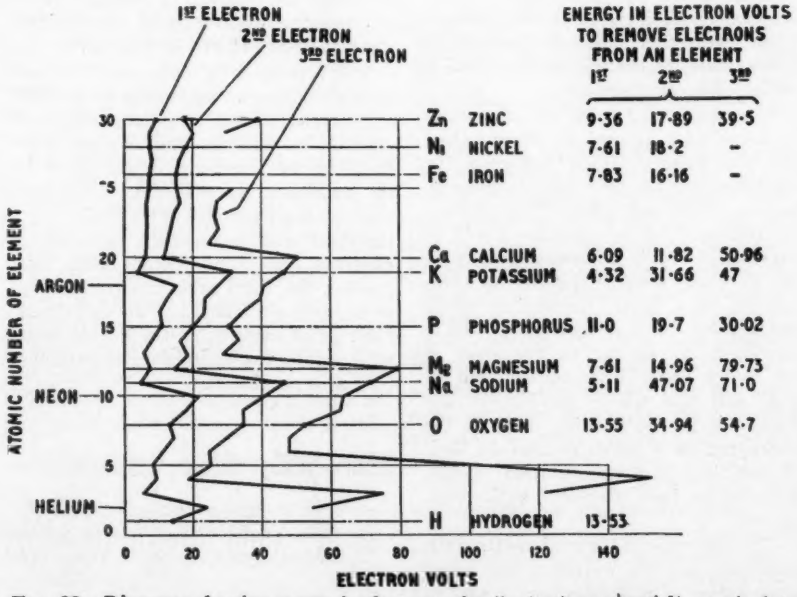


FIG. 28—*Diagrams showing energy in electron volts (ionization potential) required to remove first, second or third electrons from an element*

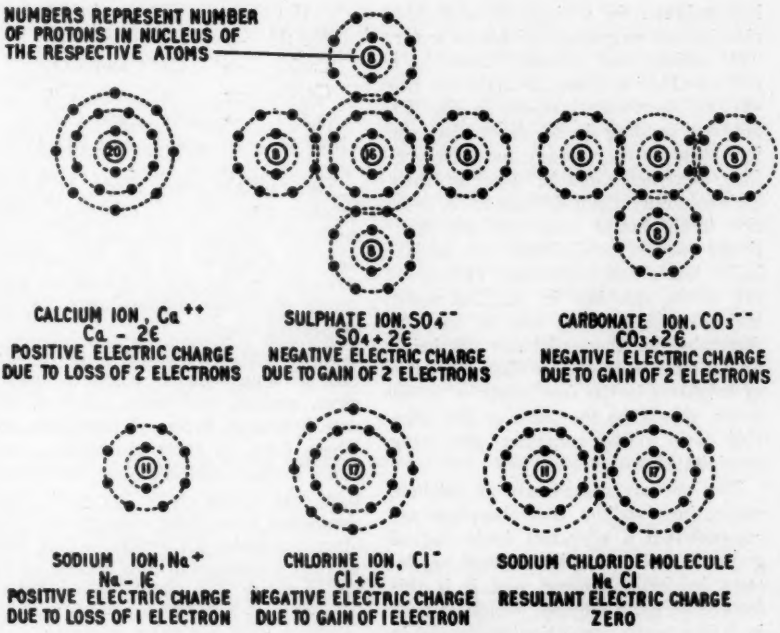

NUMBERS REPRESENT NUMBER OF PROTONS IN NUCLEUS OF THE RESPECTIVE ATOMS
CALCIUM ION, Ca ++
Ca - 2ε
POSITIVE ELECTRIC CHARGE DUE TO LOSS OF 2 ELECTRONS
SULPHATE ION, SO4 --
SO4 + 2ε
NEGATIVE ELECTRIC CHARGE DUE TO GAIN OF 2 ELECTRONS
CARBONATE ION, CO3 --
CO3 + 2ε
NEGATIVE ELECTRIC CHARGE DUE TO GAIN OF 2 ELECTRONS
SODIUM ION, Na +
Na - 1ε
POSITIVE ELECTRIC CHARGE DUE TO LOSS OF 1 ELECTRON
CHLORINE ION, Cl -
Cl + 1ε
NEGATIVE ELECTRIC CHARGE DUE TO GAIN OF 1 ELECTRON
SODIUM CHLORIDE MOLECULE
Na Cl
RESULTANT ELECTRIC CHARGE ZERO

FIG. 29—*Diagram of various ions and NaCl molecule showing their electronic arrangement*

in what is known as ionic binding. For example, the calcium ion Ca−2e has an electronic arrangement of 2.8.8 with a positive electric charge, while the sulphate ion $SO_4 + 2e$ has a negative electric charge and an electronic arrangement as shown in Fig. 29, in which the outer shell of each oxygen atom has eight electrons and the outer shell of the sulphur atom has eight electrons, each oxygen atom sharing two electrons with the sulphur atom. (The sulphate ion is an example of co-valent binding.) Both ions have a stable electronic arrangement but they have opposite electric charges which will hold and bind them together when they make contact. The compound of $CaSO_4$ is therefore an example of ionic binding between the calcium ion and the sulphate ion with the sulphate ion itself as an example of co-valent binding. Fig. 29 illustrates the electronic arrangements of various ions and compounds and shows how they tend to a stable electronic configuration.

A sodium atom has eleven electrons arranged 2.8.1. The outermost electron can be comparatively easily removed and the sodium ion which results has an electron arrangement of 2.8 which is extremely stable. In the same way, the electron arrangement of a chlorine atom is 2.8.7 so that it has a strong tendency to acquire another electron when it becomes a chlorine ion with 2.8.8 electrons, another very stable electron arrangement. Due to their extremely stable electronic arrangements with a small resultant electrical charge and their comparatively

low weights, the sodium ion and chlorine ion are extremely soluble in water. The sodium and chlorine atoms in a sodium chlorine molecule share the two valency electrons as shown in Fig. 29, but the bonding is so slight that the ions separate very readily and are therefore extremely soluble. Due to their high solubility, chlorides remain in solution in the boiler water and are practically never precipitated at normal boiler water concentrations. The measure of the chlorides in the feed water and the boiler water can be used to determine whether sulphates are being precipitated in the boiler since the ratio of sulphates in the feed water to boiler water should be the same as the chloride ratio if no sulphates are being precipitated.

The various compounds of calcium, magnesium, sodium, and phosphate are composed of a co-valent ionic radical group bonded to an ionic metal or element by ionic binding, and it is this feature of ionic binding, which is used in boiler water conditioning to obtain the precipitation of the undesirable calcium and magnesium ions in the form of sludge and to leave in solution the ions which are very soluble and can be removed by blowing down.

When an acid, salt or a base is added to the feed or boiler water, the compound dissociates into ions to a greater or lesser degree, largely determined by the valency and the temperature. The more dilute the solution is, the greater is the percentage of the molecules ionized and, in general, the higher the valency, the less the degree of ionization.

When a compound is present in the boiler water or is added to the water, a large proportion of the compound splits up into ions which, in their movements in the liquid, reform and divide repeatedly, but for any given conditions there is a constant proportion divided into ions.

Some of the compounds met on this subject divide into ions as follows:—

$$H_2O \rightarrow H^+ \text{ and } OH^-$$
$$NaOH \rightarrow Na^+ \text{ and } OH^-$$
$$CaCO_3 \rightarrow Ca^{++} \text{ and } CO_3^{--}$$
$$CaSO_4 \rightarrow Ca^{++} \text{ and } SO_4^{--}$$
$$Na_2CO_3 \rightarrow 2Na^+ \text{ and } CO_3^{--}$$
$$Na_3PO_4 \rightarrow 3Na^+ \text{ and } PO_4^{---}$$

The radicals move about as a unit because they have a relatively stable electronic configuration and the loss or gain of electrons in the ionization is governed by the division into the most stable electronic arrangement for the respective ions.

The water therefore contains a mixture of ions such as calcium, magnesium, sodium, carbonate, sulphate, silicate, hydrogen, hydroxyl, phosphate, etc. These ions, in their movements, may make contact and combine, the attraction which they have for each other depending upon their valency and their atomic or molecular weight so that when there is a mixture of ions present in the boiler water any combinations which occur follow definite preferred lines and this fact is used in boiler conditioning. The preferential tendency for some ions to combine is used in boiler conditioning where, for example, sodium is used as a carrier for carbonate and phosphate conditioning because the sodium ion is much more soluble in water than the calcium and magnesium ions. Essentially the problem is the precipitation of the calcium and magnesium present in the water so that the compounds formed give a soft sludge and not a hard scale.

Carbonate and phosphate conditioning with sodium as the carrier, were proposed by Dr. R. E. Hall (12) in America many years ago, and he has recently suggested and tested the use of potassium (13), as an alternative to sodium, as a carrier for the phosphate ion owing to undesirable concentrations of sodium hydroxide causing caustic corrosion in hideouts which may exist due to defective boiler circulation or design. Both these elements, i.e., sodium

and potassium, have a valency of one, have a very stable electronic structure in their ionic form and are very soluble in water.

If the boiler water contains ions of calcium, carbonate, sulphate, sodium and phosphate, the calcium and phosphate ions combine preferentially into tricalcium phosphate, while the sodium ions combine with the carbonate and sulphate ions to give sodium carbonate and sodium sulphate if sufficient concentration is allowed to occur, observing that the sodium ion is extremely soluble because its electronic configuration of 2.8 is extremely stable, and its weight is comparatively small. In the same way the chlorine ion is very stable with an electronic structure of 2.8.8 and this is the reason why sodium chloride is extremely soluble in water because the respective ions are very stable and have little tendency to bind with other ions.

The conditioning salts which are commonly used at present, such as sodium carbonate, sodium hydroxide and trisodium phosphate, are therefore added in the desired proportions so as to effect the required interchanges with the sodium and calcium ions to give sodium carbonate and sodium sulphate, which are very soluble, and tricalcium phosphate which is insoluble and precipitates.

SOLUBILITY DATA OF SCALE FORMING SUBSTANCES AND SODIUM COMPOUNDS

Since calcium sulphate is the main hardness forming substance its solubility is of considerable interest. It can exist in three forms of solids:—gypsum, anhydrite and hemihydrate. Fig. 30 (11) shows its solubility with temperature, from which it will be seen that its solubility decreases rapidly as the temperature is increased. Fig. 30 (11) also shows the solubilities of calcium hydroxide and magnesium hydroxide.

The relative values of the data from which the curves are plotted at the higher temperatures can be more clearly seen from Table 21.

The low solubility of $CaCO_3$ and $Mg(OH)_2$ is clearly shown by these figures.

The solubility of trisodium phosphate in water (16) is shown by Fig. 31. When the sodium ions are exchanged for calcium ions, the tricalcium phosphate which is formed is practically

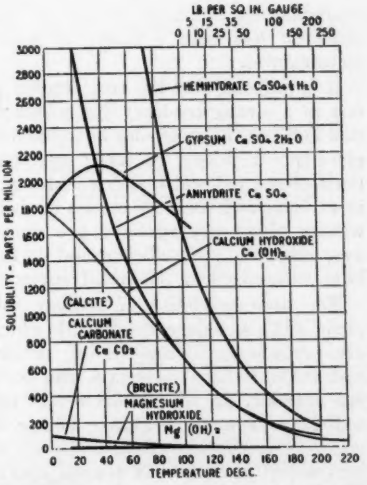


FIG. 30—*Solubility curves of scale-forming substances*

TABLE 21.—SOLUBILITY—PARTS PER MILLION (11)

Temperature, deg. C.	Temperature, deg. F.	Hemihydrate, p.p.m. $CaSO_4$	Anhydrite, p.p.m. $CaSO_4$	Calcite, p.p.m. $CaCO_3$	Calcium hydroxide, p.p.m. $Ca(OH)_2$	Magnesium hydroxide, p.p.m. $Mg(OH)_2$
100	212	1,645	650	14·8	658	4·5
150	302	530	222	7·3	225	2·2
200	392	165	76	4·8	99	0·8

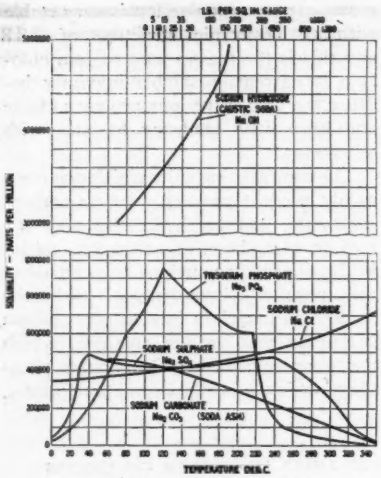


FIG. 31—*Solubility curves of sodium compounds in water*

insoluble, its solubility being of the order of less than 5 p.p.m. at boiler temperatures.

It is probable that the precipitation is due to a strong tendency for combination between the molecules of tricalcium phosphate resulting in large aggregations of the molecules which resist any re-division and settle by reason of their weight. Such aggregations are moreover relatively self-sufficient and do not bind themselves to the metal surfaces.

The high solubility of sodium sulphate (14) is shown in Fig. 31 which also shows the solubilities of sodium hydroxide, sodium carbonate, and sodium chloride. It will be seen that the sodium compounds (15) are soluble in water up to concentrations not likely to be reached in boilers in normal operation except in hide outs. Even at a temperature of 636 deg. F. (335 deg. C.) corresponding to a boiler pressure of 2000 lb. per sq. in., the solubility of trisodium phosphate is 8000 p.p.m.

The curves given in Figs. 30 and 31 are in every case for a single compound in water. Boiler feed water, however, contains a variety of compounds, and the solubility data for any given compound is appreciably affected by the presence of other compounds.

Referring to Fig. 32, curve 1 shows the solubility of $CaCO_3$ in water while curve 1a shows the solubility of $CaSO_4$ in water, these curves being similar to those given in Fig. 30, for calcite and anhydrite respectively. If two salts such as $CaCO_3$ and $CaSO_4$ are together in solution in water their solubilities are interdependent and the respective solubilities of $CaCO_3$ and $CaSO_4$ in the presence of each other in water are shown by curves 2 and 2a in Fig. 32 (17). If, however, the two component system changes to a multi-component system by the addition of another salt or salts, the respective solubilities are still further modified. Solubility curves for a three-component system of $CaCO_3$ and $CaSO_4$ in water with various concentrations of NaCl, NaOH and Na_2SO_4 are shown by curves 3 to 6 and 3a to 6a in Fig. 32 (17). The addition of NaCl has little effect on the solubility of $CaCO_3$ but substantially increases the solubility of $CaSO_4$ as shown by curve 3a. NaOH, when added, as shown by curves 4 and 5, has little effect so far as

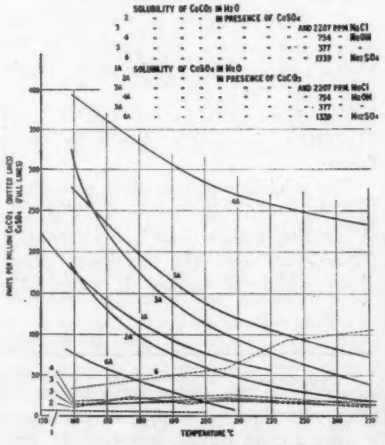


FIG. 32—*Diagram showing change in solubility of $CaCO_3$ and $CaSO_4$ in various solutions*

$CaCO_3$ is concerned but, as shown by curves 4a and 5a considerably increases the solubility of $CaSO_4$. When Na_2SO_4 is added, the solubility of $CaCO_3$ is increased as shown by curve 6 and curve 6a shows that the solubility of $CaSO_4$ is reduced, probably because of the common SO_4 ion which is present. The curves, however, show that the general trend of the solubilities of the major calcium compounds in boiler water is similar to the simple systems and they illustrate the complex nature of the problem of controlling the concentrations of any given compounds in the boiler water.

One of the earliest methods of boiler water conditioning was based on the control of the relative amounts of carbonate to sulphate in the water with the object of ensuring the precipitation of calcium in a calcium carbonate sludge, while retaining sulphate in the solution in balance with sodium. If the two salts $CaCO_3$ and $CaSO_4$ are in solution together in water, their solubilities are interdependent, and if the CO_3/SO_4 ratio exceeds the ratio of their solubility product, calcium carbonate is precipitated. Sodium carbonate was therefore added to the water to control the CO_3/SO_4 ratio at the point where calcium carbonate would be precipitated in a soft sludge. Later work, however, has shown that sodium chloride, caustic soda and sodium sulphate, all reduce the equilibrium value of the CO_3/SO_4 ratio to an extent depending on the amount of salt added and the temperature, sodium sulphate having the most pronounced effect. The CO_3/SO_4 ratios corresponding to the solubility curves in Fig. 32 are given in Fig. 33. The curves show how the CO_3/SO_4 ratio varies with temperature and different concentrations of additional sodium salts, and illustrate the difficulty of controlling any two given compounds such as carbon-

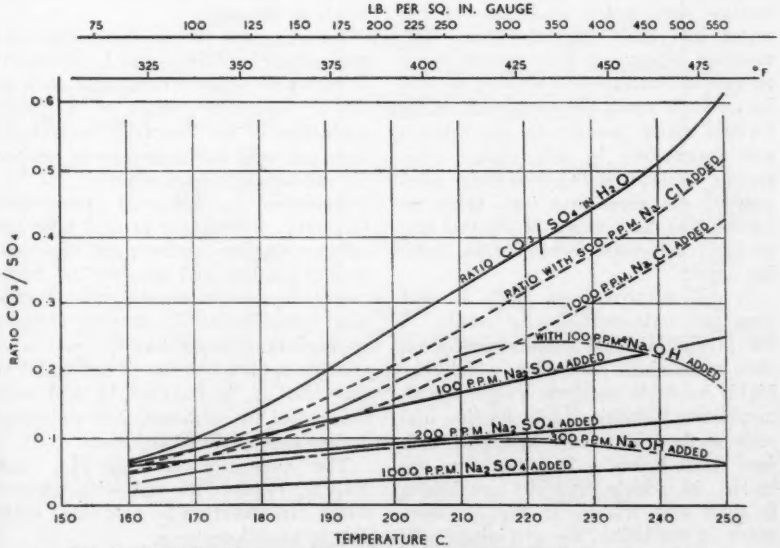

LB. PER SQ. IN. GAUGE
75 100 125 150 175 200 225 250 300 350 400 450 500 550
325 350 375 400 425 450 475 °F
RATIO CO3 / SO4
0·6
0·5
0·4
0·3
0·2
0·1
0
RATIO CO3 / SO4 IN H2O
RATIO WITH 500 P.P.M. Na Cl ADDED
1000 P.P.M. Na Cl ADDED
WITH 100 P.P.M. Na OH ADDED
100 P.P.M. Na2 SO4 ADDED
200 P.P.M. Na2 SO4 ADDED
300 P.P.M. Na OH ADDED
1000 P.P.M. Na2 SO4 ADDED
150 160 170 180 190 200 210 220 230 240 250
TEMPERATURE C.

FIG. 33—*Ratio CO_3/SO_4 as varied by temperature and addition of different concentrations of sodium salts*

ate/sulphate ratio to ensure that the precipitation of the desired compound is obtained.

Modern boiler water conditioning is therefore based on the control of alkalinity, the maintenance of zero hardness in the boiler water, and a reserve of phosphate in the boiler. Reagents may be supplied to promote the removal of scale forming matter as a flocculent sludge and oxygen scavengers may be supplied to remove residual dissolved oxygen.

LIME AND SODA CONDITIONING

Calcium hydroxide (slaked lime) is used to remove alkaline hardness and any magnesium compounds. Sodium carbonate (soda ash) is used to remove the other calcium compounds and the calcium compounds which are formed by the reactions between the calcium hydroxide and the magnesium compounds. The combination of these treatments is known as the lime and soda treatment and is commonly used to deal with natural waters before the water is supplied to the boilers. The reactions involved by the lime and soda treatment are shown in Table 22 which is largely self-explanatory. The salts present are largely ionized in the water and the corrective salts added dissociate in the water into their respective ions. The modified mixture of ions present, leads to desired combinations between certain ions which result in compounds being formed which precipitate the calcium and magnesium in soft sludge compounds instead of hard scaling compounds, the remaining ions being so soluble that they remain in solution and are not troublesome from the scale forming aspect.

It will be seen from Table 22 that lime and soda conditioning results in the precipitation of calcium carbonate and magnesium hydroxide which are highly insoluble and form a light friable precipitate. Conditioning by the lime and soda method is usually applied to the feed water before it is delivered to the boiler, in which case the precipitate is light and friable. If the reactions occur in the boiler, the precipitate will form a thin friable porous scale which is easily removed.

The complete reactions with lime and soda conditioning give zero hardness in the water, i.e., the calcium and magnesium have been removed. If preliminary water treatment is not used, the alkaline hardnesses will be precipitated by the heating in the economizer and the boiler as a soft sludge or scale but the non-alkaline hardnesses will require to be treated by the addition of sodium carbonate to prevent scale.

The theoretical ratios between the corrective salts and the salts to be removed are shown in the Table and are obtained by inserting the respective molecular and atomic weights in the chemical formulæ as shown in the example in the table.

As previously shown, the calcium and magnesium hardnesses can be expressed in terms of a single compound such as $CaCO_3$ and this permits of a simple evaluation of the theoretical weights of lime and soda ash necessary to remove the calcium and magnesium.

Reference to Table 22 shows that $Ca(OH)_2$ is required to deal with the calcium alkaline hardness and the magnesium alkaline and non-alkaline hardnesses. The reactions with the magnesium non-alkaline hardnesses produce an equivalent amount of calcium non-alkaline hardness so that it can be taken that Na_2CO_3 is required to deal with the sum of the initial calcium and magnesium non-alkaline hardnesses.

The quantities of $Ca(OH)_2$ and Na_2CO_3 required to deal with a given water can therefore be calculated quite simply as follows:—

(a) Estimate the $Ca(OH)_2$ equivalent to the sum of the calcium alkaline

TABLE 22—LIME AND SODA TREATMENT FOR REMOVAL OF CALCIUM AND MAGNESIUM FROM FEED WATER

	A SCALE PRODUCING COMPOUND AND THE IONIZED FORM IN WHICH IT EXISTS IN SOLUTION IN THE MAKE UP FEED WATER	B SALT TO PROVIDE THE NECESSARY EXCHANGE OF IONS TO AVOID HARD SCALE FORMATION		RESULTANT SALT PRECIPITATING AS A THIN SOFT POROUS SCALE OR SLUDGE	SALT REMAINING IN SOLUTION IN THE BOILER WATER	WATER FORMED IN COMPLETING THE EXCHANGE	NUMBER OF LBS OF SALT B REQUIRED FOR EACH LB. OF SCALE PRODUCING COMPOUND A
	$Ca(HCO_3)_2$ IONIZED INTO $Ca^{++} + 2(HCO_3)^-$	+ $Ca(OH)_2$ IONIZED INTO $Ca^{++} + 2(OH)^-$	FORMS	$2CaCO_3$		$+ 2H_2O$	0·45
	$CaSO_4$ IONIZED INTO $Ca^{++} + (SO_4)^{--}$	+ Na_2CO_3 IONIZED INTO $2Na^+ + (CO_3)^{--}$		$CaCO_3$	$+ 2Na^+ + (SO_4)^{--}$		0·78
	$CaCl_2$ IONIZED INTO $Ca^{++} + 2Cl^-$	+ Na_2CO_3 IONIZED INTO $2Na^+ + (CO_3)^{--}$		$CaCO_3$	$+ 2Na^+ + 2Cl^-$		0·96
	$Ca(NO_3)_2$ IONIZED INTO $Ca^{++} + 2(NO_3)^-$	+ Na_2CO_3 IONIZED INTO $2Na^+ + (CO_3)^{--}$		$CaCO_3$	$+ 2Na^+ + 2(NO_3)^-$		0·65
	$Mg(HCO_3)_2$ IONIZED INTO $Mg^{++} + 2(HCO_3)^-$	+ $2Ca(OH)_2$ IONIZED INTO $2Ca^{++} + 4(OH)^-$		$Mg(OH)_2 + 2CaCO_3$		$+ 2H_2O$	1·00
DOUBLE REACTION	$MgSO_4$ IONIZED INTO $Mg^{++} + (SO_4)^{--}$	+ $Ca(OH)_2$ IONIZED INTO $Ca^{++} + 2(OH)^-$		$Mg(OH)_2$	$+ Ca^{++} + (SO_4)^{--}$		1 LB OF $MgSO_4$ REQUIRES 0·62 LB $Ca(OH)_2$ PLUS
	$Ca^{++} + (SO_4)^{--}$	+ Na_2CO_3 IONIZED INTO $2Na^+ + (CO_3)^{--}$		$CaCO_3$	$+ 2Na^+ + (SO_4)^{--}$		0·86 LB Na_2CO_3
DOUBLE REACTION	$Mg(NO_3)_2$ IONIZED INTO $Mg^{++} + 2(NO_3)^-$	+ $Ca(OH)_2$ IONIZED INTO $Ca^{++} + 2(OH)^-$		$Mg(OH)_2$	$+ Ca^{++} + 2(NO_3)^-$		1 LB OF $Mg(NO_3)_2$ REQUIRES 0·5 LB $Ca(OH)_2$ PLUS
	$Ca^{++} + 2(NO_3)^-$	+ Na_2CO_3 IONIZED INTO $2Na^+ + (CO_3)^{--}$		$CaCO_3$	$+ 2Na^+ + 2(NO_3)^-$		0·72 LB Na_2CO_3
DOUBLE REACTION	$MgCl_2$ IONIZED INTO $Mg^{++} + 2Cl^-$	+ $Ca(OH)_2$ IONIZED INTO $Ca^{++} + 2(OH)^-$		$Mg(OH)_2$	$+ Ca^{++} + 2Cl^-$		1 LB OF $MgCl_2$ REQUIRES 0·78 LB $Ca(OH)_2$ PLUS
	$Ca^{++} + 2Cl^-$	+ Na_2CO_3 IONIZED INTO $2Na^+ + (CO_3)^{--}$		$CaCO_3$	$+ 2Na^+ + 2Cl^-$		1·11 LB Na_2CO_3

TYPICAL EXCHANGE GIVEN ON BASIS OF MOLECULAR AND ATOMIC WEIGHTS

$$\frac{MgCl_2}{24\cdot3+2\times35\cdot5} + \frac{Ca(OH)_2}{40+2\times17} = \frac{Mg(OH)_2}{24\cdot3+2\times17} + \frac{CaCl_2}{40+2\times35\cdot5}$$
$$95\cdot3 \quad + \quad 74 \quad + 169\cdot3 = 58\cdot3 \quad + 169\cdot3 \quad 111$$

$Ca(OH)_2$ REQUIRED PER LB $MgCl_2 = \frac{74}{95\cdot3} = 0\cdot78$ LB

$$\frac{CaCl_2}{40+2\times35\cdot5} + \frac{Na_2CO_3}{2\times23+60} = \frac{CaCO_3}{40+60} + \frac{2NaCl}{2\times(23+35\cdot5)}$$
$$111 \quad + 217 \quad 106 \quad = 100 \quad + 217 \quad 117$$

Na_2CO_3 REQUIRED PER LB OF $CaCl_2 = \frac{106}{111} = 0\cdot96$ LB
Na_2CO_3 REQUIRED PER LB OF $MgCl_2 = \frac{106}{95\cdot3} = 1\cdot11$ LB

Lime—$Ca(OH)_2$ Soda ash—Na_2CO_3

hardnesses and the magnesium alkaline and non-alkaline hardnesses present in the water.

(b) Estimate the Na_2CO_3 equivalent to the sum of the calcium and magnesium non-alkaline hardnesses present in the water. (This allows for the reactions between $Ca(OH)_2$ and all the initial magnesium hardnesses.)

Taking the water analysis given in Table 17 the calcium alkaline hardness plus the total magnesium hardness equals $197 + 25 = 222$ p.p.m. as $CaCO_3$. The equivalent weight of $Ca(OH)_2$ to match is $\frac{37}{50} \times 222 = 0.74 \times 222 = 164$ p.p.m. $Ca(OH)_2$ where 37 and 50 are the equivalent weights of $Ca(OH)_2$ and $CaCO_3$ respectively.

The total calcium and magnesium non-alkaline hardnesses are $67 + 25 = 92$ p.p.m. as $CaCO_3$. The equivalent weight of Na_2CO_3 to match is

$$\frac{53}{50} \times 92 = 1.06 \times 92 = 98 \text{ p.p.m.}$$

Na_2CO_3.

From the foregoing it will be seen that

(a) 0.74 lb. of $Ca(OH)_2$ (0.82 for commercial $Ca(OH)_2$) is required to deal with each lb. of calcium alkaline hardness and magnesium alkaline and non-alkaline hardnesses present in the water.

(b) 1.06 lb. of Na_2CO_3 are required to deal with each lb. of the calcium and magnesium non-alkaline hardnesses present in the water.

The above rules enable the quantities of $Ca(OH)_2$ (lime) and Na_2CO_3 (soda ash) required to deal with a given water to be calculated in a simple manner. The ionic analysis given for the same water provides the same information for the above calculations to determine the required quantities of $Ca(OH)_2$ and Na_2CO_3. The same weights can be obtained by using the atomic or molecular weights or by a detailed calculation for each compound as illustrated in Table 22.

In practice, greater quantities are required to obtain a complete chemical reaction of the salt to be removed and allowance must be made for the commercial composition of the corrective additions used. In some cases a comparatively large allowance must be made for the water of crystallization in commercial reagents.

Commercial $Ca(OH)_2$ has an equivalent weight of 41 so that the figure 0.74 becomes 0.82. Na_2CO_3 in its commercial form can be taken as having an equivalent weight of 53.

Modern high-pressure boilers are usually supplied with distilled make-up water from which the hardnesses have been almost entirely removed in evaporators. The impurities to be dealt with are those carried over with the evaporator vapor and those due to condenser leakage. These are normally so low that phosphate conditioning only is necessary, but, if the make-up is not evaporated and contains appreciable impurities, it may be economical to use lime and soda conditioning for the make-up followed by phosphate conditioning in the boiler.

Sodium carbonate (soda ash) is not suitable for final conditioning at pressures above 250 lb. per sq. in., it being difficult to maintain the CO_3^{--} formation, because it decomposes at high temperatures, and this led to the use of phosphates for final conditioning because the phosphate radical PO_4^{---} is entirely stable at all the higher operating pressures and is very satisfactory in producing a sludge precipitation instead of a scale. The decomposition of CO_3^{--}, with the soda ash treatment, into caustic soda and carbon dioxide, also tends to undue alkalinity in the boiler which is avoided by a phosphate treatment. Any treatment used must be adjusted as necessary to give the desired alkalinity of *p*H value in the boiler and soda ash may be used to control the alkalinity of the boiler water since it decomposes at high temperatures and produces sodium hydroxide.

TABLE 23—CAUSTIC SODA TREATMENT FOR REMOVAL OF CALCIUM AND MAGNESIUM FROM FEED WATER

A SCALE PRODUCING COMPOUND AND THE IONIZED FORM IN WHICH IT EXISTS IN SOLUTION IN THE MAKE UP FEED WATER	B SALT TO PROVIDE THE NECESSARY EXCHANGE OF IONS TO AVOID HARD SCALE FORMATION		RESULTANT SALT PRECIPITATING AS A THIN SOFT POROUS SCALE OR SLUDGE	SALT REMAINING IN SOLUTION IN THE BOILER WATER	WATER FORMED IN COMPLETING THE EXCHANGE	NUMBER OF LB. OF SALT B REQUIRED FOR EACH LB OF SCALE PRODUCING COMPOUND A
$Ca(HCO_3)_2$ IONIZED INTO $Ca^{++}+2(HCO_3)^-$	$2NaOH$ IONIZED INTO $2Na^+ + 2(OH)^-$	FORMS	$CaCO_3$	$+ 2Na^+ + (CO_3)^{--}$	$+ 2H_2O$	0·49
$Mg(HCO_3)_2$ IONIZED INTO $Mg^{++}+2(HCO_3)^-$	$4NaOH$ IONIZED INTO $4Na^+ + 4(OH)^-$		$Mg(OH)_2$	$+ 4Na^+ + 2(CO_3)^{--}$	$+ 2H_2O$	1·09
$MgSO_4$ IONIZED INTO $Mg^{++}+(SO_4)^{--}$	$2NaOH$ IONIZED INTO $2Na^+ + 2(OH)^-$		$Mg(OH)_2$	$+ 2Na^+ + (SO_4)^{--}$		0·66
$MgCl_2$ IONIZED INTO $Mg^{++}+2Cl^-$	$2NaOH$ IONIZED INTO $2Na^+ + 2(OH)^-$		$Mg(OH)_2$	$+ 2Na^+ + 2Cl^-$		0·84
Mg_2SiO_4 IONIZED INTO $2Mg^{++}+SiO_4^{----}$	$4NaOH$ IONIZED INTO $4Na^+ + 4(OH)^-$		$2Mg(OH)_2$	$+ 4Na^+ + SiO_4^{----}$		1·14
$Mg(NO_3)_2$ IONIZED INTO $Mg^{++}+2(NO_3)^-$	$2NaOH$ IONIZED INTO $2Na^+ + 2(OH)^-$		$Mg(OH)_2$	$+ 2Na^+ + 2(NO_3)^-$		0·54

EXCHANGE GIVEN ON BASIS OF MOLECULAR AND ATOMIC WEIGHTS

$$\frac{24\cdot3+2\times62}{148\cdot3} \quad \frac{+\ 2\times23+2\times17}{228\cdot3} \quad \frac{+\ 80}{} \qquad \frac{24\cdot3+2\times17}{58\cdot3} \quad \frac{+\ 2\times23+2\times62}{228\cdot3} \quad \frac{+\ 170}{}$$

RATIO $\frac{B}{A} = \frac{80}{148\cdot3} = 0\cdot54$

Caustic soda—NaOH

CAUSTIC SODA CONDITIONING

Sodium hydroxide (caustic soda) is sometimes used instead of the lime and soda treatment and the principal reactions involved are shown in Table 23.

Caustic soda removes the calcium alkaline hardnesses and the magnesium alkaline and non-alkaline hardnesses by precipitating calcium carbonate and magnesium hydroxide as shown in Table 23. Caustic soda, however, does not deal with calcium non-alkaline hardnesses which require sodium carbonate to effect the reactions as shown in Table 22. If magnesium alkaline hardnesses are present the reactions with caustic soda produce sodium carbonate as shown in Table 23 and the sodium carbonate thus produced will react with the calcium non-alkaline hardnesses. If insufficient sodium carbonate is produced in these reactions, sodium carbonate in addition to caustic soda requires to be added. Due to this, it is not possible to provide a simple formula for the evaluation of the required caustic soda and the amount requires to be calculated in detail for each particular water analysis. The precipitates formed by the use of caustic soda are calcium carbonate and magnesium hydroxide which do not form a hard scale. In modern high-pressure boilers the

principal use of caustic soda is to control the alkalinity or *p*H value of the boiler water.

Gloves and eyeshields should be worn when dealing with concentrated solutions of caustic soda, because it can cause serious injury to the skin and eyes if it touches them.

PHOSPHATE CONDITIONING

Various aspects of phosphate conditioning have been referred to in the section headed "Sodium phosphate compounds," which gives particulars of the various phosphates normally used. Phosphate conditioning is now the preferred treatment for high-pressure boilers, because, at boiler pressures above 250 lb. per sq. in., the carbonate radical in sodium carbonate breaks up into sodium hydroxide and carbon dioxide, giving rise to undue alkalinity, whereas the PO_4^{---} ion is completely stable and very soluble at all the higher boiler pressures in use.

Sodium metaphosphate, or hexametaphosphate, disodium phosphate and trisodium phosphate are the phosphates most commonly used.

Sodium hexametaphosphate, monosodium phosphate and disodium phosphate are converted into trisodium phosphate in the boiler water in the presence of sodium hydroxide as shown in Table 24. This is due to their dissociation into their respective ions followed by a combination of the hydrogen and hydroxyl ions to form water, thereby leaving in solution the sodium ions and phosphate ions in the ratio of three to one.

If trisodium phosphate is used, it dissociates directly into the ratio of three sodium ions to one phosphate ion.

When calcium ions are present in the water, in their movements, they make contact with the phosphate ions and combine, due to their electronic forces, etc., in the ratio of three calcium ions to two phosphate ions.

The compound thus formed, $Ca_3(PO_4)_2$, tricalcium phosphate, is practically insoluble in the molecular structure of water and is precipitated as a soft sludge. If the caustic alkalinity of the boiler water is low, say below 100 p.p.m., the calcium may be removed as dicalcium phosphate, $Ca_2H_2(PO_4)_2$, or monocalcium phosphate $Ca(H_2PO_4)_2$, both of which are more soluble than tricalcium phosphate.

TABLE 24—CONVERSION OF DISODIUM AND MONOSODIUM PHOSPHATE TO TRISODIUM PHOSPHATE BY ADDITION OF CAUSTIC SODA

A		B		B/A
Na_2HPO_4 IONISED INTO $2Na^+ + (HPO_4)^{--}$	+	$NaOH$ IONISED INTO $Na^+ + (OH)^-$	FORMS $3Na^+ + (PO_4)^{---} + H_2O$	0·28
NaH_2PO_4 IONISED INTO $Na^+ + (H_2PO_4)^-$	+	$2NaOH$ IONISED INTO $2Na^+ + 2(OH)^-$	FORMS $3Na^+ + (PO_4)^{---} + 2H_2O$	0·66
EXCHANGE GIVEN ON BASIS OF MOLECULAR AND ATOMIC WEIGHTS				
$23 + 97 + 2\times23 + 2\times17$			$3\times23 + 95 + 2\times18$	
120 200		80	164 200	36
RATIO $B/A = 80/120 = 0{\cdot}66$				

Disodium phosphate—Na_2HPO_4
Monosodium phosphate—NaH_2PO_4

TABLE 25—PHOSPHATE TREATMENT FOR REMOVAL OF CALCIUM AND MAGNESIUM AND TO AVOID CAUSTIC CONCENTRATION IN BOILER FEED WATER

A SCALE PRODUCING COMPOUND AND THE IONISED FORM IN WHICH IT EXISTS IN SOLUTION IN THE MAKE UP FEED WATER	B SALT TO PROVIDE THE NECESSARY EXCHANGE OF IONS TO AVOID HARD SCALE FORMATION		RESULTANT SALT PRECIPITATING AS A THIN SOFT POROUS SCALE OR SLUDGE	SALT REMAINING IN SOLUTION IN THE BOILER WATER	WATER FORMED IN COMPLETING THE EXCHANGE	NUMBER OF LBS OF SALT B REQUIRED FOR EACH LB OF SCALE PRODUCING COMPOUND A
$3Ca\,CO_3$ IONIZED INTO $3Ca^{++}+3(CO_3)^{--}$	$2Na_3PO_4$ IONIZED INTO $6Na^{+}+2(PO_4)^{---}$	FORMS	$Ca_3(PO_4)_2$	$+6Na^{+}+3(CO_3)^{--}$		1·09
$3Ca\,SO_4$ IONIZED INTO $3Ca^{++}+3(SO_4)^{--}$	$2Na_3PO_4$ IONIZED INTO $6Na^{+}+2(PO_4)^{---}$		$Ca_3(PO_4)_2$	$+6Na^{+}+3(SO_4)^{--}$		0·80
$3Ca\,Cl_2$ IONIZED INTO $3Ca^{++}+6Cl^{-}$	$2Na_3PO_4$ IONIZED INTO $6Na^{+}+2(PO_4)^{---}$		$Ca_3(PO_4)_2$	$+6Na^{+}+6Cl^{-}$		0·99
$3Mg(HCO_3)_2$ IONIZED INTO $3Mg^{++}+6(HCO_3)^{-}$	$2Na_3PO_4$ IONIZED INTO $6Na^{+}+2(PO_4)^{---}$		$Mg_3(PO_4)_2$	$+6Na^{+}+6OH^{-}+6CO_2$		0·75
$3Mg\,SO_4$ IONIZED INTO $3Mg^{++}+3(SO_4)^{--}$	$2Na_3PO_4$ IONIZED INTO $6Na^{+}+2(PO_4)^{---}$		$Mg_3(PO_4)_2$	$+6Na^{+}+3(SO_4)^{--}$		0·91

Trisodium phosphate—Na_3PO_4

Table 25 gives the reactions which occur with sodium phosphate compounds and calcium and magnesium compounds in water. It will be seen that the sodium ions are left in solution in balance electrically with the carbonate, sulphate and chloride ions which formed part of the calcium salts and the calcium is precipitated with the phosphate.

With the removal of the calcium, any magnesium ions which may be present will combine with hydroxyl ions and will precipitate as $Mg(OH)_2$, which will be enmeshed in the tricalcium phosphate sludge and rendered harmless. The removal of the calcium ions also helps to prevent silicates forming scale by leaving the silicates in solution.

Sodium hexametaphosphate is commonly used in feed water because the change to trisodium phosphate takes place gradually and so avoids precipitation in the feed system. The rate of change can be considerably increased by heating or the addition of acid or alkali.

Trisodium phosphate is commonly injected direct into the boiler to avoid precipitation in the feed system or economizers. Phosphate treatment, it is claimed, has the advantage that it will dissolve any calcium deposits which may have been deposited.

An excess of phosphates is usually supplied to the boiler to maintain a reserve in solution in the boiler to ensure complete reactions and to deal with any increase in the ingress of scale forming solids.

A suitable reserve is 25 to 70 p.p.m. in terms of PO_4^{---}.

The use of sodium as the carrier for phosphate conditioning leaves the sodium in solution in the boiler. Dr. R. E. Hall, in America, has suggested that this may lead to strong sodium hydrox-

ide concentration in hide outs and has recently proposed and tested the use of potassium as a carrier instead of sodium (13). He points out that potassium is very similar to sodium in its properties and has better solubility characteristics while avoiding the dangers of strong caustic concentrations.

The various sodium phosphate compounds are similar in their action in preventing scale formation but differ in their effect on the boiler water alkalinity.

The choice for use, therefore, depends upon the control of alkalinity and their effect increases in the order of sodium hexametaphosphate, disodium phosphate and trisodium phosphate. Consideration also requires to be given to the desirability of the avoidance of precipitation in feed piping and economizers.

COLLOIDAL AND COAGULANT TREATMENT

In some circumstances, not clearly understood, calcium carbonate, magnesium hydroxide and phosphate sludges may adhere to boiler surfaces, and to prevent this possibility, coagulant or colloidal treatment may be used.

Substances vary as to their solubility. In a true solution, the solute will consist of units which are not larger than single molecules, and the molecules are dispersed equally throughout the liquid. The molecules of some substances, however, or molecules of two substances present, may combine to form larger particles which settle in the liquid, due to the action of gravity, and are then said to be insoluble. In some cases, the insoluble solid particles are so small that they settle very slowly or remain suspended in the liquid indefinitely. The suspended particles consist of clusters of molecules or atoms and are known as colloids. A colloidal system consists of at least two substances one of which acts as a central connecting link to the other substance or substances in a symmetrical structure and the structure as a whole has a resultant electric charge due to the electronic configuration and this charge prevents them forming into greater clusters and keeps the colloidal particles dispersed in the liquid by the repelling action of their similar charges.

A nucleus of an atom has dimensions of the order of 10^{-12} cm., while the zone of the electrons surrounding the nucleus is of the order of 10^{-8} cm. Any particles having dimensions smaller than 10^{-7} cm., i.e., 10^{-8} cm., will exist in water in true solution. The average size of a colloidal particle is approximately 10^{-6} cm. The size or length of small particles is usually expressed in Angstrom units, a unit which is represented by the symbol A. 1A is 10^{-7} mm. to (10^{-8} cm.) i.e., one ten millionth of a millimeter.

Particles up to 10A will exist in true solution in water. Particles of 10 to 1000A (10^{-7} to 10^{-5} cm.) in diameter, are considered to be of colloidal size and will remain in suspension while particles greater than 1000A ($^{-5}$ cm.) in diameter will settle due to gravity. As a comparison for size, particles of about 1500A are the smallest objects that can be seen by means of an ordinary microscope, while the largest known inorganic molecules have diameters of about 10A. A molecule of water is about 4A diameter.

A very important physical factor of colloids is the relatively extremely large surface area these particles present due to the extreme extent of the sub-division which occurs. For example, a cube of colloidal substance 1 cm. across its faces will have its surface area multiplied one million times when it is dispersed colloidally in water.

Colloids can be used to remove scale forming ions with opposite electric charges because attraction and bonding occur due to the opposite electric charges.

The neutralization of the electric charges which tend to keep the colloidal particles apart allows the colloidal particles to coagulate together and with the scale forming solids so that the agglomeration increases in weight until precipitation or a floc occurs. Precipitation takes place in the form of a loose soft sludge which will flow with the current of the liquid and can be blown down.

Substances such as starch, tannin, gels, casein, etc., are colloids in water and because of the large surface area provided by the very large number of very small particles and their similar electric charges, they are intimately dispersed throughout the water and become intimately but loosely bonded to any precipitating salts to form a flocculent mass which forms a floating easily removed sludge.

Substances such as sodium aluminate, ferric and ferrous sulphate, etc., in water give rise to the formation of their hydroxides which act in a similar way to colloids and promote coagulation with scale forming precipitates.

The presence of a colloid within the matrix of any scale has the effect of reducing the mechanical strength of the scale and facilitating its removal. If oil is present, the colloid will combine with the oil and assist in making it harmless or removing it.

Ferric and ferrous sulphate are used as coagulants in the external treatment of water and, in conjunction with lime and caustic soda, produce a floc of ferric hydroxide which assists in the removal of suspended matter.

Sodium aluminate $Na_2Al_2O_4$ is also used with the lime soda treatment as a coagulant. Sodium aluminate is a compound of sodium oxide Na_2O and aluminum oxide Al_2O_3. In solution in water, it can exist as a molecular dispersion or in a colloidal dispersion, and it is probable that the latter is the important phase. The colloidal dispersion contains particles of aluminum hydroxide, the surface layer of which is ionized and the system can be expressed as follows:—

$$\begin{matrix} Na^+ \\ 2Na^+ \\ \end{matrix} \; .. \; \begin{matrix} (OH)_2Al^- \\ (OH)Al_2^{--} \\ AlO_3^{---} \end{matrix} \; \Big[Al(OH)_3, \text{aq.} \Big] \; \ldots \; 3Na^+$$

where the formula inside the bracket represents the nature of the solid phase in the colloid particle and the symbols outside indicate an electrical surface double layer (18).

The colloidal aluminum hydroxide dispersed in the water is negatively charged while magnesium hydroxide which may be present colloidally in the water is positively charged. Coagulation into a floc therefore occurs between the aluminum hydroxide and the magnesium hydroxide due to their opposite charges. There is no similar action between aluminum hydroxide and calcium carbonate precipitates, but such precipitates may be enmeshed in the matrix of the colloidal flocculent structure. Particles of other scale forming solids are carried by the floc and prevented from forming hard scale.

The action of sodium aluminate is improved by the addition of tannin which helps to form a coagulated floc of the finely divided precipitates so that the resultant aggregate is free flowing and can be blown down from the boiler easily.

Sodium aluminate together with magnesium hydroxide is also useful in precipitating silica from solution and avoiding hard silicate scaling. To ensure the removal of the silica it has been found to be important that magnesium is present in the water and if sufficient magnesium hydroxide is not available magnesium sulphate is sometimes added to the sodium aluminate tannin solution to prevent scaling due to silica.

OXYGEN SCAVENGING

It is now the invariable practice to supply a modern high-pressure boiler with de-aerated water but there is always the possibility that unusual circumstances may result in undesirable oxygen ingress. To meet this, and to supplement the mechanical de-aeration provided, sodium sulphite Na_2SO_3 is sometimes used to mop up any residual oxygen. Sodium sulphite should not be used to deal with any large quantities of oxygen, say above 0.2 ml/litre, because the amount required would unduly increase the total dissolved solids in the boiler.

In the water, Na_2SO_3 ionizes into $2Na^+$ and SO_3^{--} and combines with the dissolved oxygen in the water as follows:—

$$4Na^+ + 2SO_3^{--} + O_2 \rightarrow 4Na^+ + 2SO_4^{--}$$

If sodium sulphite is used, a slight excess of 20 to 30 p.p.m. should be carried in the boiler water.

CONDITIONING FOR CAUSTIC CRACKING

The conditions causing caustic cracking are still far from clearly understood, but it would appear to be due to very strong concentrations of sodium hydroxide, NaOH, in the base of a crack, or fissure. Experiments in the U.S.A appear to show that caustic cracking will not occur if the concentration of NaOH is less than 100,000 p.p.m. This is, of course, a higher concentration than is likely to occur as an overall value in boiler water but it can occur in cracks and hide outs.

Research has indicated that attack is inhibited if the surface is coated with sodium sulphate or sodium carbonate and on this basis boiler water is conditioned against caustic cracking by maintaining sufficient sodium sulphate and/or sodium carbonate to ensure their deposition when the concentration of sodium hydroxide reaches 100,000 p.p.m.

Sodium carbonate is liable to decomposition into sodium hydroxide while sodium sulphate is stable. Sodium sulphate is therefore the preferred inhibitor.

Straub in the U.S.A. established curves of ratios of $Na_2SO_4/NaOH$ and $Na_2CO_3/NaOH$ at different boiler temperatures which would ensure the deposition of Na_2SO_4 or Na_2CO_3 and these are given in Fig. 34 (19).

There is a lot of experience to show

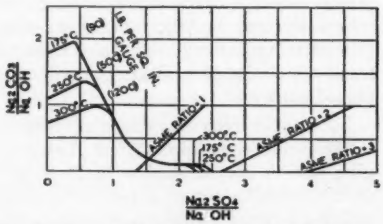


FIG. 34—*Curves of ratios $Na_2CO_3/NaOH$ and $Na_2SO_4/NaOH$ required in boiler water to prevent caustic cracking*

that if boiler water is conditioned so that the ratios are above the curves given, satisfactory protection will be afforded against caustic cracking. In 1936, the American Society of Mechanical Engineers laid down that the ratio of sodium sulphate Na_2SO_4 to the total alkalinity, in terms of sodium carbonate Na_2CO_3, should be not less than 1 to 1 up to boiler pressures of 150 lb. per sq. in., 2 to 1 for boiler pressures of 150 to 250 lb. per sq. in., and 3 to 1 for boiler pressures over 250 lb. per sq. in., and these ratios are indicated in the diagram (19).

It has been noted that sodium chloride seems to assist in inhibiting caustic cracking. Sodium silicate appears to accelerate caustic cracking but the addition of a combination of iron and aluminum has been successful in counteracting the effects of sodium silicate.

Straub and Bradbury's investigations (20) into these aspects appear to show that for steam pressures up to 250 lb. per sq. in. caustic cracking may be prevented by maintaining a sodium chloride ratio in the boiler water greater than 0.6 times the total alkalinity expressed as Na_2CO_3 along with a sodium sulphate content greater than 1.0 times the total alkalinity. For a steam pressure of 350 lb. per sq. in. these sulphate or chloride ratios appear to be effective but may require to be somewhat larger. For steam pressures between 500 and 1400 lb. per sq. in. their results indicate that the presence of a soluble R_2O_3 content of greater than 0.6 times the SiO_2 content of the boiler water prevents caustic cracking. The R_2O_3 content may be a combination of iron and aluminum oxides and in the majority of the cases investigated aluminum as Al_2O_3 appeared to predominate (20).

Knowledge on this subject, however, is still far from complete and at present it is desirable to carry as high a sodium sulphate concentration as can be accepted within the total dissolved solids considered acceptable for a given boiler design. This will give the conditions least likely to allow caustic cracking to occur.

British Standard 1170-1947 recommends that the ratio of sodium sulphate Na_2SO_4 to the caustic alkalinity in terms of NaOH should have a minimum value of 2.5 at all times in all boilers with riveted or welded drums, which have not been stress relieved.

BOILER BLOW DOWN AND RECIRCULATION

The blow-down from a boiler is usually strongly alkaline and in land practice the blow down is usually effected continuously and is often passed through suitable equipment to use the heat in the blow-down for feed or other heating purposes, or it may be used in a water conditioning plant or a de-aerator, wherein the heat and the alkalinity may be utilized to increase the *p*H value of the feed water so as to prevent corrosion in the feed system and economizer.

In marine practice, it is almost the invariable practice in water tube boiler installations to provide make-up feed which has been doubly distilled to reduce the solid impurities to a minimum and so reduce the blow-down required as much as possible. Where continuous blow-down is practiced, the blow-down is sometimes led into the fresh water evaporator to conserve heat and water.

In land power stations, there is a growing practice of taking water from the boiler and discharging it through the economizer, back into the boiler. The quantity of water circulated in this way is about one to three percent of the boiler output.

The alkalinity of such water is in the range of a *p*H value of 11 to 12 and this enables a lower *p*H value to be carried in the feed water before the mixing than would otherwise be the case to ensure that the economizers are protected against corrosion.

The total solids entering the boiler are thus reduced and the boiler can be operated with a lower total dissolved content or a smaller blow-down. Further, the continuous flow of such water provides continuous protection, particularly on light loads and where chemical conditioning is effected intermittently.

CONTROL OF BOILER WATER CONDITIONING AND ALKALINITY

It will be appreciated from the information already discussed that water treatment is a complex subject with a multiplicity of factors and that the water treatment adopted should be studied with a knowledge of the composition of the water used and any scale which may result. It is advisable, therefore, to con-

sult the specialists in this field and follow their recommendations. For marine service, guidance has been provided by British Standard Specification 1170/-1947, which should be consulted for full details. It advises, broadly, that the boiler water should be conditioned as follows:—

(a) The alkalinity to phenolphthalein, in terms of $CaCO_3$, should be kept within the limits 125-250 p.p.m. with a recommended range of 175-225 p.p.m. for both water-tube and Scotch boilers. If the total dissolved solids exceed 2000 p.p.m., the alkalinity should be increased 125 p.p.m. per 1000 p.p.m. additional dissolved solids but should not exceed 1000 p.p.m. to avoid corrosion of brass mountings.

(b) The caustic alkalinity, in terms of $CaCO_3$, should be kept within 100-200 p.p.m., with a recommended range of 125-175 p.p.m. for both water-tube and Scotch boilers. This corresponds to 80-160 p.p.m. and 100-140 p.p.m. in terms of sodium hydroxide NaOH. If the dissolved solids exceed 2000 p.p.m. the caustic alkalinity should be increased by 100 p.p.m. (in terms of $CaCO_3$) or 80 p.p.m. (in terms of NaOH) per 1000 p.p.m. additional dissolved solids. The caustic alkalinity should not exceed 850 p.p.m. (as $CaCO_3$) or 680 (as NaOH) to avoid corrosion of brass mountings.

(c) The chlorides in the boiler water should be kept below 120-480 p.p.m. in water-tube boilers, according to the design and rating of the boiler, and below 3600 p.p.m. for Scotch boilers.

(d) The total dissolved solids should be kept below 500 to 2000 p.p.m. for water-tube boilers, according to design and rating, as necessary to avoid priming and carry over, and below 15,000 p.p.m. in Scotch boilers.

(e) The hardness should be zero.

(f) A reserve of phosphate of the order of 25 to 70 p.p.m. should be carried in a water-tube or a Scotch boiler.

(g) A reserve of sulphite, as Na_2SO_3, of 20-30 p.p.m. should be carried in both types of boilers.

(h) The sulphate, measured as Na_2SO_4, should be 2.0 times the caustic alkalinity in terms of $CaCO_3$ or 2.5 times the caustic alkalinity in terms of NaOH, for both types of boilers.

(i) The dissolved oxygen content (of the feed water) should be between 0.02 and 0.05 ml/litre, the former figure being desirable for highly rated water-tube boilers and the latter for all other boilers.

In land power stations, a representative set of figures of American practice gives the total dissolved solids in the feed water as ranging from 0.2 to 14 p.p.m. with an average of 2.6 p.p.m. while the total dissolved solids in the boiler water ranged from 47 to 1000 p.p.m. with an average of 360 p.p.m.

Chlorides pass through a boiler unchanged and the measure of the chlorides in the boiler water to the chlorides in the feed water gives a measure of the concentration of the solids in the water in the boiler. If no sulphate scale is forming, then the sulphate ratio will be the same as the chloride ratio but if it is less, sulphate scale is being formed.

The alkalinity is a measure of the total bicarbonates, carbonates and hydroxides in the water. The bicarbonates, carbonates and hydroxides may be in their ionic form or in suspension bonded with metallic ions. The alkalinity may be measured in terms of a single substance such as $CaCO_3$ or NaOH. 50 parts of $CaCO_3$ are equal to 40 parts of NaOH and the terms are interchangeable in that ratio when used as a measure of other substances. Alkalinity due to bicarbonates and carbonates is called carbonate alkalinity, while alkalinity due to hydroxides is known as caustic alkalinity. Hydroxides and bicarbonates cannot exist together because they combine to form carbonates.

Caustic alkalinity is a measure of the

hydroxyl ions present in the water balance with or bonded with metallic ions. Caustic alkalinity is therefore a measure of the OH present in the water above the number of hydroxyl ions corresponding to the neutral value of *p*H, which is 7 for the standard pressure and temperature, and is usually expressed in terms of $CaCO_3$.

To prevent corrosion it has been shown that it is desirable to maintain the *p*H value of the boiler water between 11 and 12 and, because of the concentration which occurs in the boiler, and the feed water should be controlled between *p*H values of 8.5 and 9.5.

Corrective chemicals to prevent scale formation have their effect on the *p*H value of the boiler water, since any excess left in solution may alter the relative concentrations of hydrogen and hydroxyl ions. Substances are said to be alkaline in character if, when dissolved in water, they supply hydroxyl ions or, by the reactions which occur, they increase the number of hydroxyl ions present in the water. Conversely, substances which supply hydrogen ions when dissolved in water, or are responsible for reactions which result in an increase in the number of hydrogen ions, are said to be acidic. Acids added or formed in the water increase the hydrogen ion concentration while alkalis or salts with alkaline effects increase the hydroxyl ion concentration. For example, if sea water is allowed ingress to a boiler, the magnesium chloride, $MgCl_2$, combines with the water and hydrochloric acid HCl is produced together with a precipitation of magnesium hydroxide $Mg(OH)_2$ as follows:—

$MgCl_2 + 2H_2O$ forms $Mg(OH)_2 + 2HCl$,

the hydrochloric acid being produced in the dissociated form of hydrogen ions H^+ and chlorine ions Cl^-, so that the hydrogen ion concentration is increased and therefore the possibilities of corrosion.

The measurement of the pH value of the boiler water is not a very convenient process because of the low hydrogen ion concentration at the *p*H value range usually worked. It is therefore much more convenient to measure the alkalinity of the boiler water and to work within a prescribed range.

The p.p.m. of hydrogen ions and hydroxyl ions corresponding to different *p*H values are given in Table 3.* Pure water has a *p*H value of 7 with 0.001 p.p.m. of hydrogen ions and 0.0017 p.p.m. of hydroxyl ions.

The addition of bicarbonates, carbonates and hydroxides will increase the number of hydroxyl ions. The bicarbonates will decompose with heating giving metallic ions, carbonate ions and carbon dioxide gas $\overline{CO}_2$. With correct conditioning, the calcium and magnesium ions will have been removed together with the balancing amount of carbonate ions and hydroxyl ions, and any carbonate and hydroxyl ions remaining will be in solution in balance with sodium ions. The hydroxyl ions increase the hydroxyl ion concentration while the carbonate ions react with hydrogen ions in the water to form carbon dioxide gas which also results in an increase in the hydroxyl ion concentration.

The substances used in boiler water conditioning which increase the *p*H value of sodium hydroxide NaOH, sodium carbonate Na_2CO_3, trisodium phosphate Na_3PO_4 in its anhydrous form, and commercial trisodium phosphate $Na_3PO_4 12H_2O$.

When sodium hydroxide NaOH is added to the water it dissociates into its ions, Na^+ and OH^- so that, theoretically, the OH^- concentration is directly increased and could be calculated from the respective relative weights of Na^+ and OH^-, 23 and 17.

When sodium carbonate Na_2CO_3 is added to the water, the dissociation gives two sodium ions $2Na^+$ for each carbonate ion CO_3^{--}. Some of the car-

* Not reproduced in this printing.

bonate ions react with hydrogen ions H^+ in the water thus:—

$$CO_3^{--} + H^+ \text{ form } \overline{CO}_2 + OH^-$$

The two surplus electrons in the radical CO_3^{--} ion are used to supply the one short in the hydrogen ion and the other makes the combination of the hydrogen and oxygen atoms into an hydroxyl ion. An hydrogen ion is thus neutralized and an hydroxyl ion formed with the evolution of carbon dioxide as a gas so that the hydrogen ion concentration is reduced and the hydroxyl ion concentration increased. The sodium ions remain in solution and the water, as a whole, remains electrically neutral.

When trisodium phosphate remains in solution in the boiler water it is in the ionic form of $3Na^+$ and PO_4^{---}.

The phosphate ion will combine with hydrogen ions, as they make contact, with reversible reactions as follows:—

(1) $PO_4^{---} + H^+ \rightleftarrows (HPO_4)^{--}$

(2) $(HPO_4)^{--} + H^+ \rightleftarrows (H_2PO_4)^-$

(3) $(H_2PO_4)^- + H^+ \rightleftarrows H_3PO_4$

The phosphate ions, by the combining with hydrogen ions, cause an increase in the hydroxyl ion concentration.

In each case described above, the product of the numbers of hydrogen ions and hydroxyl ions in the water is maintained constant by the further dissociation of water molecules into hydrogen and hydroxyl ions until equilibrium is reached, the resultant effect being a reduction in the hydrogen ion concentration and an increase in the hydroxyl ion concentration.

The effect on the *p*H value by additions of varying amounts of the compounds mentioned is shown in Fig. 35 (21). The extent to which such compounds dissociate in water is variable depending upon temperature and other conditions but the diagram illustrates approximately the effect obtained. For example, if a water containing NaOH has a *p*H value of 11 the addition of 300 p.p.m. of NaOH will raise the *p*H value to 12. The p.p.m. of OH^- to give varying *p*H values is shown by the dotted line.

The curves show clearly that the control necessary to maintain the boiler water within a given *p*H range such as 11 to 12 is not unduly sensitive. To obtain very high *p*H values requires very considerable additions of the suitable chemicals.

For practical convenience, boiler water control is usually carried out in terms of alkalinity but it should be appreciated that the object is to obtain the desired hydroxyl ion concentration necessary to prevent corrosion and maintain a self-repairing action on the protective film over the steel surfaces.

The total dissolved solids must be kept below the maximum permissible for the design and rating of the boiler and the treatment should be that which will give the maximum *p*H value within the permissible total dissolved solids and the desired ratios of the other compounds appropriate to the boiler and the operating conditions. The presence of undesirable solids should therefore be kept as low as practicable and the excesses of desirable compounds should be kept as close as possible to the minimum acceptable.

It will be seen from Fig. 35, that additions of sodium hydroxide have the most marked effect in increasing the *p*H value of the boiler water for a minimum increase in the total dissolved solids present after non-scaling requirements have been met.

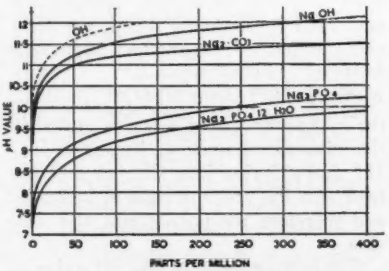


FIG. 35—*Effect on pH value by addition of varying amounts of chemicals*

CONCLUSION

Boiler corrosion and feed and boiler water conditioning involve a multiplicity of complex factors, which are strange to the average engineer.

It is not intended that this paper should be a guide to the actual water treatment to be used and it should be emphasized that it is strongly advisable to consult specialists in this field and follow their advice. It is hoped, however, that it will help to a better understanding of the factors involved.

In dealing with chemical terms and equations there are different ways of expressing the same information and alternative ways have purposely been used in the paper by way of illustration.

ACKNOWLEDGMENTS

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BIBLIOGRAPHY

(11) Partridge, E. P. Engineering Research Bulletin, No. 15. University of Michigan. "Formation and Properties of Boiler Scale."

(12) Hall, R. E., Smith, G. W., Jackson, H. A., Robb, J. A., Karch, H. S., and Hertzell, E. A. 1927. Carnegie Institute of Technology, Pennsylvania. Bulletin No. 24. "A Physico-Chemical Study of Scale Formation and Boiler Water Conditioning."

(13) Hall, R. E. 1944. Trans.A.S.M.E., Vol. 66, p. 457. "A New Approach to the Problem of Conditioning Water for Steam Generation."

(14) Schroeder, W. C., Gabriel, A., and Partridge, E. P. "Solubility Equilibria of Sodium Sulphate at Temperatures of 150 to 350 deg. C."
1935. Jl. American Chemical Society, Vol. 57, p. 1539. I Effect of Sodium Hydroxide and Sodium Chloride.

(15) Schroeder, W. C., Berk, A. A., and Gabriel, A. "Solubility Equilibria of Sodium Sulphate at Temperatures from 150 to 350 deg. C."
1936. Jl. American Chemical Society, Vol. 58, p. 843. II Effect of Sodium Hydroxide and Sodium Carbonate.

(16) Schroeder, W. C., Berk, A. A., and Gabriel, A. "Solubility Equilibria of Sodium Sulphate at Temperatures from 150 to 350 deg. C."
1937. Jl. American Chemical Society, Vol. 59, p. 1783. III Effect of Sodium Hydroxide and Sodium Phosphate.

(17) Clark, L. M., and Hunter, E. 1935. Jl. American Chemical Society, Vol. 57, p. 383. "The System $CaCO_3$-$CoSO_4$ at 159 deg. to 252 deg. and the Effects of Additions of Sodium Salts."

(18) Clark, L. M., and Price, L. S. 1933. Jl. of Society of Chemical Industry, Vol. 52, No. 6, p. 35T. "The Role of Sodium Aluminate in Accelerating the Separation of Solid Phases during Water-softening Operations."

(19) Hamer, P. "Some Problems in Water Treatment." Imperial Chemical Industries. Reprinted from the *Engineering and Boiler House Review.*

(20) Straub, G., and Bradbury, T. A. Research at the University of Illinois. "A Method of The Embrittlement Testing of Boiler Waters."

(21) Hillier, H., and Bradley, J. N. B.I.O.S. Final Report, No. 1333, Item No. 29. "Final Report on German Naval Boilers with Particular Reference to Design, Corrosion, and Boiler Feed Water Treatment." (H.M. Stationery Office, London.)

SHIPS' ELECTRICAL AUXILIARIES— A COMPARISON BETWEEN ALTERNATING AND DIRECT CURRENT DRIVES

ACKNOWLEDGMENT

This paper by MR. R. CLARK is based on an examination of the characteristics and design of direct and alternating current auxiliaries approached from the performance rather than from a highly technical viewpoint. It does not deal with the argument of AC vs. DC equipment. It appeared in the Transactions of the Institute of Marine Engineers, March, 1950.

INTRODUCTION

Electrical auxiliaries on board ship can be divided roughly into three groups:—

(a) Motors and starters with standard characteristics for either constant or variable speed drives.
(b) Motors with controllers for speed selection and usually having special features.
(c) Special purpose motors and control gear with characteristics to suit the duty.

Typical applications under each group are:—

(a) Pumps, fans, compressors, domestic machinery, workshop motors.
(b) Turning gear, small windlasses and capstans.
(c) Large windlasses and capstans, winches, steering gear, etc.

The salient features essential for marine gear are:—

Strong mechanical construction.
Accessibility for inspection and maintenance.
Adequate protection for the service condition.
Insulation of exceptional reliability.
Ease of quick repairs by ship's staff, including rewinds.
Conservative rating.

The omission of any one of these factors can only lead to trouble and probably a complete breakdown and no apology is made for stressing their importance.

It has been said that the use of a.c. machines and control gear for ship work will make a greater stock pile available, implying that any stock industrial type motor or starter of suitable output can be used on board ship. This is a dangerous fallacy which in the long run can only decrease the reliability of a ship's electrical installation. Electrics should be specially designed for marine use.

Enlarging upon the above factors, the need for a strong mechanical construction is obvious, as extra stresses and strains are encountered on shipboard due to rolling and pitching in heavy weather and vibration.

Similarly, accessibility is more important on a ship than on land. The most reliable motor or controller may give trouble and for this reason provision must be made for the engineer to carry out a repair in the easiest manner and the shortest possible time. For example, a motor (if d.c.) may with advantage have a split magnet and end bracket or easily removable bearing. A control panel may with advantage be arranged to tip forward on trunnions, without removing the service cables. All contacts subject to sparking must be easily replaced and it should be possible to replace coils without upsetting the contact adjustment.

Fig. 1 shows a d.c. motor with split magnet brackets. Fig. 2 shows a post-contact starter panel.

Correct enclosure is vital. With control gear one has not much choice; it has to be either "ventilated" or "totally enclosed." With motors one has at least four types of enclosures from which to choose. These apply equally to a.c. or d.c.

Ventilated drip-proof. This is the most common type for use below deck, complete protection is afforded against falling or splashing water.

Pipe Ventilated. These machines are totally enclosed with the exception of openings for air inlet and outlet. The openings should be flanged for trunking, but, if preferred, a cowl can be fitted over the outlet. This form of enclosure is particularly suitable for situations where the motor is exposed to a high ambient temperature, as the inlet can be trunked to a source of cool air.

Totally enclosed (fan cooled). A dust-tight enclosure in which a fan directs cooling air over the outside surface of the magnet. On the larger sizes the "Emcol" construction enables a totally enclosed machine to be built with a weight and price not greatly exceeding those of the ventilated type.

Fig. 3 gives a section through an "Emcol" type motor.

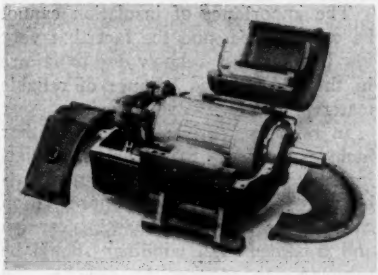


FIG. 1.—D. C. motor with split magnet and brackets showing accessibility.

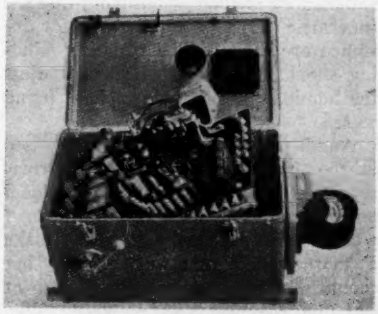


FIG. 2.—Post contact starter panel hinged forward for inspection of resistances.

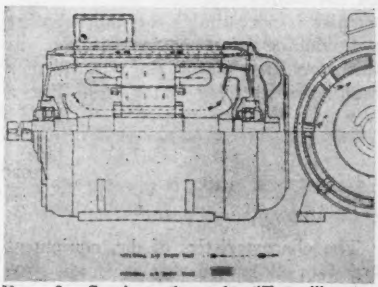


FIG. 3.—Section through "Emcol" type T. E. motor.

Totally enclosed (deck watertight). These are usually short rated machines and are totally enclosed with specially designed covers and stuffing glands. They are suitable for exposed positions on deck.

The importance of insulation cannot be overstressed, and the fact that very few breakdowns are now due to failure in this direction is because of reliable material and methods evolved.

In referring to insulation the author includes reference to the actual insulating materials and the impregnation—both of equal importance. Impregnation calls for the very best insulating varnish and treatment. All windings should be subjected to stoving to remove any moisture, and then impregnated under vacuum and pressure. This is the only satisfactory method of ensuring that the innermost turns of a field coil for instance are treated. The resulting winding should be completely proof against the humid, salt laden atmosphere found at sea.

Another point which should be stressed is the importance of winding armatures or stators of any but fractional horsepower machines, with former wound coils. Not only does this make a more reliable and sound job, but should a coil become damaged it can at least be removed and replaced. This makes for cheaper maintenance and a reduction in the bulk of spares carried. In the author's opinion thermo-setting varnish is not suitable for impregnating the winding of a marine machine, as this would not permit the removal of a faulty armature or stator coil. For a similar reason wedges are more suitable than binders for keeping coils in position.

Insulation of control gear is no less important. Although micanite is still largely used, the components allow the use of modern high grade electrical mouldings and these are now being used with great success. One must not overlook the possibility of "tracking." Gear is much more prone to this trouble at sea than on land and suitable precautions must be taken. Modern anti-tracking varnish correctly applied to all surfaces of insulation practically eliminates this risk, it being assumed, of course, that conductors and terminals are suitably spaced. To prevent corrosion all metal parts whether ferrous or non-ferrous, including cases, should be plated or specially treated before painting.

The use of waterproof resinous varnish in conjunction with vacuum and pressure impregnation used in control gear has been found very successful. It was recently brought to the author's notice that some control gear had been submerged in the Mersey for twelve weeks as the result of an accident, after which the contactor coils, after naturally drying out, were found to still stand the high voltage test applied to new gear.

The classification societies lay down maximum temperature rises.

GROUP A

D.C. Motors and Control Gear

The characteristics of d.c. equipment are so well known that it is not proposed to investigate these at any great length, beyond recalling the essential features.

The windings are invariably compound and are fitted to satisfy two requirements, starting torque and/or increase in speed at light loads. They can range from a level speed shunt machine (to which series turns are fitted for stability) to a compound machine having perhaps 50 percent speed increase at no load.

Motors with series characteristics are normally found under group B.

Most motors in this group are designed to suit the individual drive and so there are the motors for reciprocating pumps and compressors designed from the point of view of starting torque, and motors for centrifugal pumps from

the point of view of speed increase with load reduction.

In the past it has been the practice to give pump manufacturers a fairly accurate speed increase at light load to suit their impeller design. The starting requirements of this type of pump are, of course, easy.

The requirements of an ordinary ventilating fan are not onerous, the starting torque has only to overcome the inertia of the fan runner and provide constant acceleration against increasing load. When a speed range is necessary it can be provided easily by shunt field regulation, or in the case of small machines by a tapped series winding.

The speed regulation of forced and induced draught fans is more difficult because of the larger speed range required to give the steaming conditions, and it may be necessary to resort to series field regulation in addition to shunt. Increasing numbers of installations are now being provided with automatic control, of which the Bailey meter is an example, and although these can be arranged to give electrical or mechanical control, electrical is undoubtedly to be preferred.

Motors for domestic machinery are of the lowest horsepower found on board ship and are normally constant speed. They are provided with shunt windings with the addition of a series winding if necessary to provide additional torque either for starting or to deal with overloads.

Starting arrangements for this group and speed control by shunt field regulation do not present any difficulties, and starters may be either of the automatic or hand operated types. The inherent advantage of the automatic type is that the starting period is out of the control of the operator once the starting circuit has been made. They also allow the motor to be controlled by remote start and stop push-buttons or automatic devices such as a float or pressure switch.

Consider the automatic types first. The small direct-on-the-line contactor type has been proved very successful in use with constant speed motors up to 5 h.p. This particular design incorporates a patented feature allowing the motor field to build up before automatically switching the armature across the line. This gives high torque at starting and reduces the current kick when compared with a direct-on starter without this feature.

For over 5 h.p. (or variable speed motors below) and up to 40 h.p. then the automatic "2-step" contactor starter should be considered. This again is a simple type of starter incorporating only a single step of main resistance.

For the largest applications a multi-step automatic contactor starter is supplied. These can be provided with electromagnetically operated timed accelerators to enable motors with large speed ranges to start on full field and then automatically accelerate to a speed corresponding to the setting of the shunt field regulator. Thus the motor always starts on full field irrespective of the position of the regulator. The motor can also be arranged to slow down to its full field speed before stopping where this requirement is desirable.

In the hand operated class one has the choice of face-plate post-contact or drum designs.

The inherent difference with these types is that the starting period is entirely in the hands of the operator, who must exercise a reasonable amount of care during the starting performance. Ammeters and/or running indication devices are refinements and usually supplied as extras.

All these designs except the "face-plate" are provided with a contactor to make and break the main current on the first step in order to prevent burning at the contacts.

The starting requirements for fans and centrifugal pumps are not onerous and starters for these drives are usually designed to pass full load current on the

first step. Exceptions are reciprocating drives and motors which require rather more torque at starting to overcome static friction.

A.C. Motors and Control Gear

Centrifugal pumps and fans offer the most attractive drive for a.c. motors on ships. The starting conditions are easy and in many cases a constant speed motor can be used. Where it is necessary to vary the speed of the drive then an arrangement utilizing tapped or separate windings is often satisfactory and allows the use of a squirrel cage design.

It is only when a speed range is required with infinitely variable speed between the limits that one has to turn to other types and those found most suitable are the slip-ring and commutator designs.

The chief disadvantage of the squirrel cage motor has always been a low starting torque and high initial current kick and it has often been necessary to resort to the much higher priced slip-ring motor and control gear. The factor of high initial current alone is of considerable importance where the capacity of the generating plant is limited, as for example on board ship. Anything that can be done to reduce this current without reduction in torque, must, of necessity, be a factor of extreme importance, particularly with the motors connected to the emergency alternator, whose generating capacity is even more limited than the main alternators.

The patented "Trislot" gives the advantages of considerably higher torque than the ordinary squirrel cage type, or, where the starting torque is not so important (as with a centrifugal drive) a considerably lower starting current. This type of motor can be used for many drives which would ordinarily require a much more expensive and bulky slip-ring motor and stator-rotor starter.

The lower starting current gives a further advantage in that it allows a simple "direct-on" starter to be used. A "direct-on" starter as well as being the simplest is also the smallest and cheapest. It also removes one source of possible trouble, i.e., with star-delta starting on types of drive where the load increases with acceleration such as fans, or pumps starting against open valves, it sometimes happens that change over to delta is made before the motor reaches full speed in star, giving a change-over current almost equal to the direct-on starting value.

In any event whenever the change over is made the current is likely to reach a very high value, and is liable to set up high stresses in the motor windings during the transitional stage between breaking circuit of the star connected winding and re-making in delta. Auto-transformer starting can, of course, be employed, but the starters are expensive and as with star-delta starters are liable to give a momentary high current peak during change over to full voltage.

Below are given comparisons of the approximate starting characteristics of the four types of motors it is proposed to review.

TABLE 1—COMPARISON OF STARTING CHARACTERISTICS FOR MEDIUM SIZE MOTOR

	Squirrel cage	"Trislot"*		Slip-ring	"N-S" variable speed
Torque per cent	100	100	200	100	100
Starting current per cent	600¶	350¶	380/400¶	125†	100‡

*Designed to give starting torque required for drive.
†With suitable starter.
‡With slow speed starting.
¶Direct-on starting

In the case of star-delta starters the starting values of torque and current are both reduced to approximately one-third of the direct-on values. With auto-transformer starters the torque and current are reduced as the square of the percentage tapping.

It may be mentioned that the "Trislot" has been standardized for use on some

new a.c. tankers now being built and motors representing over 1200 h.p. are being supplied for pumps, boiler fans, compressors and steering gear. The "Trislot" high torque low current squirrel-cage a.c. motor is a machine which operates during the starting period on the current displacement principle. It combines the best possible performance at full speed with the highest torque efficiency, not only at starting but also during the accelerating period. The stator is of standard electrical and mechanical design. The rotor construction is essentially different from that of any other kind of squirrel-cage motor based on the principle of current displacement (such as deep bar rotors, Boucherot rotors, etc.) and produces maximum starting performance combined with high efficiency and power factor at full load. The core is built up in the normal manner but has a special arrangement of slots, characteristic of the "Trislot" principle.

The arrangement is shown diagrammatically in Fig. 4, which for the purpose of clarity shows part of the rotor winding only. There are three rows of slots at different distances from the periphery. The outer row of slots (1) is connected with the air gap by narrow slits in the usual manner. It contains the bars (A) of a normal squirrel-cage winding of comparatively high resistance and high thermal capacity. Alternate slots of the outer row are connected by narrow slits with slots of the middle (2) and innermost (3) rows. The winding accommodated by rows 2 and 3 consists of turns (B) of which one part lies in row 2 and the other part in row 3, the two parts being displaced relative to each other by approximately one pole pitch.

Motors designed for this duty can be used for the most exacting starting conditions, where hitherto slip-ring motors provided with starters suitable for twice full load torque have been used exclusively, since the latter require three times full load current or more at starting, and, moreover, peaks of the same magnitude may occur several times during the starting period, depending on the skill of the operator in manipulating the starting apparatus. Such peaks may be minimized only by incorporating costly features in the starting rheostat.

With the direct-on started motor there is only one peak, that occurring at starting, and during the whole acceleration period the current falls smoothly

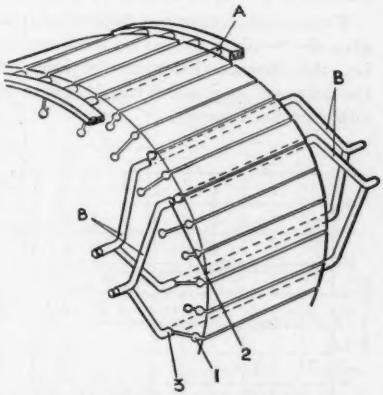


FIG. 4—*Part of "Trislot" rotor winding*

and evenly to the current required at full load, and this cannot be influenced in any way by the operator.

The direct started motor is also the ideal solution for every drive where the simplest control gear arrangement is desired. This is, of course, especially the case in connection with all automatic and remote control drives, irrespective of their starting torque requirements.

It is usually not sufficiently appreciated that slip-ring motors used in connection with contactor starters and controllers often show more than one starting kick of up to 350 percent of the full load current on intermediate steps.

Pump and Fan Drives. For driving centrifugal machines such as large fans and pumps, where a comparatively low

starting torque but a constant accelerating torque is required, motors with special characteristics have been developed, and lower starting torques at standstill with reduced starting currents for direct start are provided (Fig. 5).

For reciprocating drives such as compressors it is frequently desirable to arrange for a higher value of starting torque, and values up to 200 percent or more if necessary can be provided with a starting current in the vicinity of 400 percent full load as shown in Fig. 6.

Two-speed motors can be arranged to give the required torque on both speeds, i.e., the characteristics on the lines of the curves Fig. 5 and 6 can be given at either or both speeds.

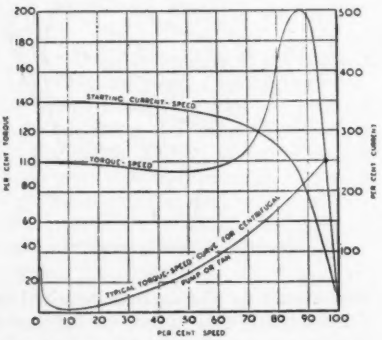


FIG. 5—*"Trislot" performance curves for centrifugal drives*

Starting Performance. The most important electrical advantage is that the "Trislot" high torque low current motor produces a higher torque efficiency, i.e., more ft.-lb. per unit of current, than any other system without sacrificing to any appreciable extent the performance at full load, and this is the true criterion of the excellence of any motor, designed on the current displacement principle. This is due to the special arrangement of the slots and the judicious proportions and distribution of the starting and main windings, which cause high reactance of the latter at start, consistent with low tooth saturation and leakage at full speed. The torque is maintained at a high level throughout the major part of the accelerating period, i.e., the speed-torque curve does not show any marked "trough." This is due to the choice of a definite winding pitch of the main winding, selected in every case to avoid the detrimental influence of the higher harmonics of the field, which, as is well known, tend to create a counter torque. Because of this favorable speed torque curve the motor is free from "crawling,"

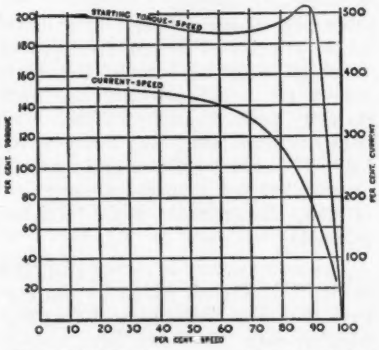


FIG. 6—*"Trislot" performance curves for reciprocating drives*

that is, starting but failing to run up to speed.

In general, the frame size of a "Trislot" motor will not exceed that of the equivalent high torque motor of ordinary construction or that of the equivalent slip-ring motor (less slip-ring enclosure when this is external to the latter machine). The cost of a "Trislot" motor is normally appreciably lower than that of a slip-ring motor, the starting equipment is cheaper, and the running efficiency approximately the same.

In the case of motors driving plant which has to be automatically started and stopped, the elimination of complicated control gear will result in considerable savings. Further, maintenance (admittedly low even in the case of a slip-ring motor) is further reduced.

Marked savings in both capital cost and running costs are thus obtained.

Variable Speed Motors. The great majority of drives will be covered by the use of the "Trislot" motor but where it is desired to obtain a speed control such as is required by the induced and forced draught fans (with electrical control) then the application of the slip-rings or "N-S" design must be considered and it is proposed to assess the merits of each type.

Consider briefly the regulation of a slip-ring motor with a variable resistance in the rotor circuit. At full load and synchronous speed (ignoring losses) the motor draws, say, 100 h.p. from the line and delivers (the mechanical equivalent of) 100 h.p. at the shaft. If it is now desired to run at half speed assuming constant torque over the speed range (under which condition 50 h.p. will be delivered at the shaft), it will still draw 100 h.p. from the line and the remaining 50 h.p. must be dissipated in the resistance. In running at reduced speed, the rotor generates a voltage across its terminals proportional to the difference between synchronous speed and its actual speed (termed the slip), which will force current through the resistance, and by suitably adjusting the latter the desired speed may be obtained.

At no load, with no current drawn from the line (still assuming an ideal motor without losses), there is no energy input which can be dissipated in the resistance. Therefore no speed reduction is possible at no load. In practice, the speed of an induction motor with rotor resistance is greatly dependent on the load (see Fig. 7).

Whilst the above example is based on the assumption of constant torque, the same considerations apply for any drive and torque-speed characteristics, i.e., at half the speed 100 percent of the output is dissipated in the rotor regulating resistance. This is a natural law which is applicable to any series resistance regulation independent of the current system a.c. or d.c., and for that matter also applies to mechanical slip drives such as magnetic or hydraulic clutches, etc.

If means can be found to utilize the slip energy generated in the rotor by returning it to the line, the speed can be made independent of the load and the high losses in the resistance can be saved.

This is the principle of the "N-S" motor. In place of slip-rings, the rotor

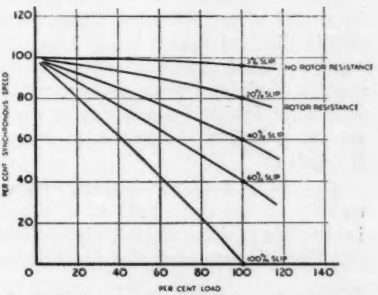


FIG. 7—*Load-speed curves for slip-ring motor using rotor-resistance*

is provided with a commutator in order that the frequency in the external rotor circuit, which otherwise varies from 50 cycles at standstill (on a 50-cycle supply) to zero at synchronism, may be kept constant. The constant frequency allows the insertion into the rotor circuit of a transformer with its primary winding connected to the supply and of which the secondary voltage is varied. As the secondary voltage is varied so the rotor adjusts its speed to generate a similar voltage; but unlike the slip-ring motor with rotor resistance, the voltage that has been adjusted in the transformer secondary is independent of the rotor current and therefore the motor speed is independent of the load. (In actual practice, there is a small variation with load due to ohmic and inductive resistance.)

In the "N-S" variable speed a.c. commutator motor however, the stator is

similar to that of a normal induction motor and is connected to the supply. The armature with its commutator is essentially similar to that of a d.c. motor, with the addition of an auxiliary commutating winding at the bottom of the slots and serving the same purpose as interpoles on d.c. machines. In this way the causes of sparking are suppressed at source. It is this feature that makes the commutation of an "N-S" motor so excellent and ensures long commutator and brush life.

Speed variation is obtained in practice by means of an induction regulator—a simple piece of apparatus of high efficiency, connected to the fixed brushes and capable of giving infinite speed variation within the limits of speed range, which can be as high as 1:10 or even greater if required.

The "N-S" motor with shunt characteristics is the equivalent to a Ward-Leonard or positive and negative booster set. There is, however, also in existence an "N-S" motor with series characteristics which has a similar performance to a d.c. motor.

The precise function of this speed regulator cannot be fully explained without considerable technical description, but in effect it takes from the motor rotor excess energy not required at low speeds (which energy would be wasted in resistances in the case of variable speed slip-ring motors) and returns it to the supply. For instance, considering the 100 h.p. motor again, at synchronous speed the induction regulator takes no part in the transmission of energy, the motor draws 100 h.p. from the line and delivers (the mechanical equivalent of) 100 h.p. to the shaft. At speeds below synchronism, energy generated in the rotor is returned by the induction regulator to the line. At speeds above synchronism (which condition is obtainable with the "N-S" motor without auxiliary apparatus) the regulator supplies to the rotor from the line the additional energy

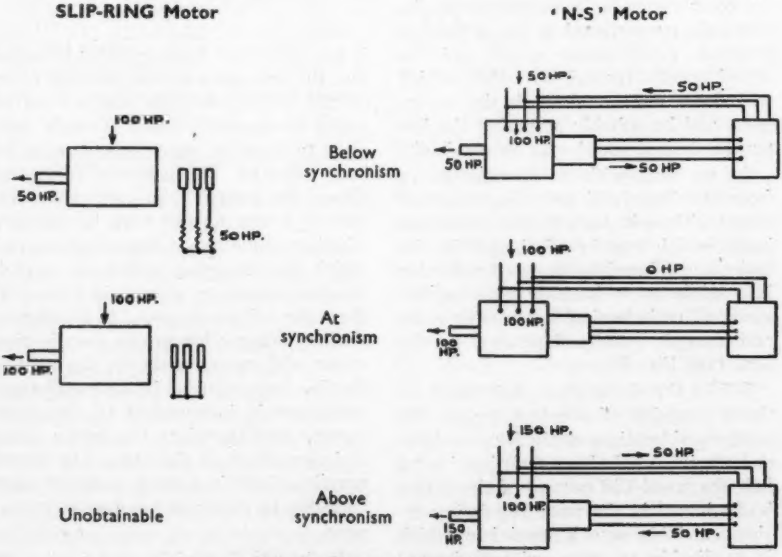


FIG. 8—*Energy balance diagram*

required to make up the total power at the shaft.

The energy balance diagram Fig. 8 helps to illustrate these points.

Thus by adjusting the voltage of the induction regulator, which can be done by rotating a hand-wheel or by automatic means, the "N-S" motor can be caused to run at any speed within the design range.

The fact that at constant torque a constant energy is supplied to the stator of an "N-S" motor, independent of speed, has special advantages in connection with the protection of the motor.

The efficiency curve resembles in shape that of a normal induction motor. The power factor curve is of somewhat different shape and may be higher at partial loads than at full load, which is of particular advantage for ship board use. The design of the machine incorporates provision for a compensating winding which raises the power factor above that of the comparable normal induction motor.

This type of motor can be made reversible when required.

A.C. Control Gear. At the present time research is being carried out on the many problems confronting the designer of a.c. control gear to ensure that the best designs are available for marine use.

Amongst the points which will have to be considered are:—

(1) The question of circuit protection for motors, including single-phase protection and with overloads calibrated to cater for the starting conditions of direct-on-starting.
(2) Reverse power relays for alternators.
(3) Parallel operation of alternators.
(4) Synchronizing alternators.
(5) The question of admissibility of oil-immersed gear particularly in starters, oil switches and transformers.
(6) Voltage regulation for alternators.
(7) Short circuit currents in a.c. systems.

Protection of Motors. In the author's opinion circuit breaker protection is preferable to fuses, if advantage is to be taken of direct-on starting. Fuse protection would have to be suitable to cater for the direct-on current kick and it is debatable whether adequate protection will be given under normal running conditions. In addition no protection will be given for single phasing if one fuse blows. Blown fuses would also require hand replacement.

An automatic resetting overload is much to be preferred, preferably with a mechanical time lag, the operation of which is unaffected by ambient temperature. Lags of the oil dash-pot type are not so reliable as the viscosity of the oil varies with changing ambient temperature.

Probably owing to the fact that a.c. power for ships' auxiliaries has been little used in this country, some designs at present on the market are quite unsuitable for marine duties. The same problems of construction, insulation, vibration and saline conditions have to be met, that have been overcome so successfully on d.c. ships.

(1) Single Phasing. A frequent cause of breakdown of polyphase motors is their accidentally running on single phase owing to an open circuit occurring in one lead while the motor is running. An open circuit in one of the supply leads will not stop the motor, it will continue to run as a single phase motor with an increased current in the other two supply leads. With a delta connected stator and a failure of the above description the current entering the stator from the remaining leads will usually divide itself unequally between the three stator windings, the greater amount flowing in that winding which is connected directly across the remaining two supply leads. Under certain conditions of load this can be well above the setting of the

overload which is not carrying this internal current, the overload usually being connected into the supply from the main (Fig. 9). It is possible to connect

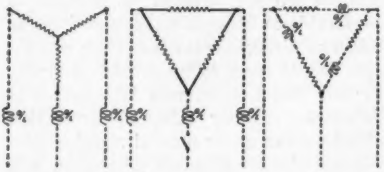


FIG. 9—*Single phasing (a) star connexions, complete protection given by overloads (b) delta connexions, three wires out, incomplete protection given (c) delta connexions, six wires out, complete protection given*

an overload coil in each phase but this would mean taking six leads out of the motor making the terminal box extremely bulky. It would, however, ensure that normal overload protection would cover single phasing.

Fig. 10 will show that on the opening of one of the supply leads to a delta-connected motor, how the current divides unequally.

At 75 percent of full load the opening of a supply lead results in the line current rising to 147 percent full load and the current in the heavily loaded phase to 180 percent of its full load value. Thus an overload release coil designed to prevent the line current exceeding 50 percent overload will actually permit one of the stator windings of the motor to carry 80 percent overload continuously.

There are a number of devices on the market to give complete protection to single phasing but the author has yet to see one that is suitably designed for marine duty.

Complete protection against single phasing for a star-connected motor is much simpler as the current flowing in the overload is the same as that flowing in the phase to which it is connected (Fig. 9a).

(2) Reverse Power Relays for Alternators. Reverse power relays for alternators are certainly necessary. With

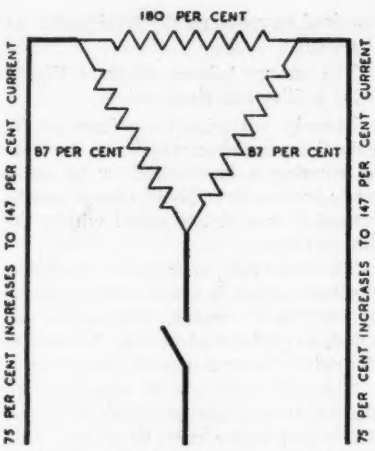

180 PER CENT
87 PER CENT
87 PER CENT
75 PER CENT INCREASES TO 147 PER CENT CURRENT
75 PER CENT INCREASES TO 147 PER CENT CURRENT

FIG. 10—*Single phasing with 75 per cent load delta connected*

two machines running in parallel, when one engine has for some reason or other stopped, precautions must be taken to prevent the shut down machine being driven by its alternator running as a motor, from power supplied from the other alternator.

(3) Parallel Operation of Alternators. There is a considerable difference between the parallel operation of d.c. generators and a.c. generators or alternators when used for the supply of ship installations. With suitably designed d.c. generators load sharing and parallel operation can in most cases be solved without reference to the characteristics of the engine governors, assuming the governors to be of a normal type.

When two d.c. generators are paralleled any desired division of load can be obtained by the simple adjustment of excitation, since the current delivered by either machine is proportional to the difference between its induced and terminal voltages. Also, since the speeds of the two machines need not be identical, the governors can automatically take care of the change in load imposed

by the new conditions of excitation. With two alternators in parallel the speeds are of necessity identical and the division of the Kw. load is therefore unrelated to the excitations (except in a minor degree) but is dependent on the power supplied by the prime movers. In other words the required division of Kw. loading is obtained by direct adjustment of engine throttles. If the excitation of one machine is raised it will not cause that machine to take more of the total Kw. load but will produce a wattless circulating current which will lower its own power factor, at the same time raising the power factor of the other machine. The power factors of the alternators, or in other words, the amounts of wattless Kva. which they deliver, are thus controlled by excitation.

Briefly the power supplied, or "power component" is controlled by the prime mover (in the case of Diesels by the engine governor), and the "wattless component" by the excitation and governed by automatic voltage regulators.

There are a number of well-designed automatic voltage regulators on the market that are suitable for marine duty. Automatic control of the power component is a problem for the engine designer, to provide a suitable design of governor, lively in response and capable of adjustment.

(4) Synchronizing Alternators. It is certainly necessary to synchronize two or more alternators when paralleling, in three particulars:—

(a) Speed.
(b) Volts.
(c) Phasing-in.

The engine speed and alternator phasing-in (a) and (c) are related problems, and concern the engine designer who must provide remote control of speed from the switchboard.

The voltage component (b) is usually adjusted by a hand operated regulator, indication being given by voltmeter, the automatic regulator then taking charge. The engineer is thus only concerned with speed adjustment of the prime mover to enable him to phase-in, suitable indication being given, and parallel by hand.

The problem of synchronization had been stressed in various papers on the subject, but it is felt that the difficulties with this operation have been overrated. The author is of the opinion that it is unnecessary to fit complicated automatic synchronizing devices which can only be a possible source of trouble.

(5) Oil Immersed Gear. The grave fire risk, and precautions to be taken to eliminate spilling of oil, in the author's opinion rules out any form of oil switch where the oil is in contact with arcs for ship-board use. It is claimed that this type of gear reduces over-all size compared with modern well designed air break control gear. This is very doubtful and taking into account the space required for the oil container the space factor is in favor of the air break design. Oil switches are also very messy when maintenance work is undertaken and this again increases the fire risk.

(6) Voltage Regulation for Alternators. The voltage regulation of an alternator feeding a load of lagging power factor is of the order of 30 percent on a power factor of 0.8 lagging. With an alternator of this regulation a change of voltage following the removal of full load occurs, in two stages, firstly, an instantaneous increase of approximately 6 percent followed by a gradual increase of the voltage to 30 percent above full load voltage. The first increase is due to magnetic leakage, and the second increase due to the removal of the armature reaction. The slow change of the second large increase is caused by eddy currents in the field system. Thus, if it is required to keep the voltage within ± 1 percent of nominal value, some form of quick acting voltage regulator is essential. The voltage regulator limits the maximum sudden demands which

can be taken from the alternator, and thus the maximum size of motor which can be started from an alternator of a given capacity. The figure usually taken for this motor size is 50 percent of the alternator output.

(7) Short Circuit Currents in A.C. Systems. The author sees no reason why this problem should be more difficult to control than that which has been done on d.c. installations.

Admittedly the short circuit protection of individual motors differs somewhat from that employed on d.c. on account of the time lag characteristics of the a.c. overload to cater for the "run-up" of an a.c. motor at start. Providing the correct type of motor is fitted the capacity of the starter circuit breaker need be no larger than that used in a d.c. system.

The magnitude of alternator short circuit currents is governed by the alternator capacity and must not be confused with the short circuit currents experienced on land installations.

Providing the main breakers fitted are in line with the size of alternator no serious difficulties should be found in giving complete protection.

GROUP B

D.C. Motors and Control Gear for Speed Selection

Turning gear motors are invariably series wound and speed selection is obtained by a drum controller giving four or five steps of plain series control in each direction of rotation, ranging from full speed down to a crawl for fine engine adjustment.

Starting conditions are generally severe and although the torque required usually falls directly the engine has made a revolution or two it is impossible to know how long the motor may have to run and for this reason it is usual to rate liberally both the motor and control gear. Although the main current is handled by the drum contacts, a circuit breaking contactor should be fitted as policy to make and break the main circuit under all conditions.

The requirements of an anchor windlass are a falling speed-load characteristic, which will allow the motor ultimately to stall on overloads while still maintaining a live pull; and a slow creep speed with reduced torque available, with a readily stalling characteristic. This enables the anchor to be run up against the hawse pipe without damage to either. In the event of the windlass being used for warping duty as well, then an additional feature is advisable giving high speed at light load for hauling in slack rope.

These requirements can be met by three types of control, depending upon the size of the vessel, viz., drum, contactor and variable voltage.

For the smaller coaster type a drum controller giving speed selection and operated by a hand-wheel is quite suitable. The motor should have a falling speed characteristic as given by a series wound machine. In practice however a small shunt winding also is fitted to stabilize it and prevent an excessive speed at light load.

Normally five or six steps of speed control, obtainable by series resistance, suffices and although main current should be made and broken by a circuit breaking contactor, the resistance steps can be shorted by the drum contacts.

The slow creep speed required on the first step for running the anchor against the hawse can be readily obtained by armature diverter control which assists in giving a more steady speed than plain series resistance.

The series wound motor will produce a very large torque on overloads and to

safeguard the equipment should the anchor meet a sudden obstruction, a torque limiting device should be incorporated. This has the effect of inserting main resistance, enabling the motor still to maintain a live pull, until the obstruction is cleared.

The additional requirement, that of obtaining a high speed at light loads, is provided by a "load discriminator" as fitted to cargo winches. This enables the motor automatically to accelerate due to field weakening when the load conditions permit.

The usual protective features of over-current and under-voltage should be fitted. Enclosure is a further point to be considered and the controller should be suitable for either mounting on deck with varying degrees of watertightness, or for mounting below deck, the operating handle then being carried up to a pedestal, fitted either with or without an illuminated ammeter.

The main resistances must of necessity be fitted below deck because free ventilation is necessary to dissipate the heat.

For larger vessels the characteristics required of both the motor and the system of control remain similar, but owing to the larger horsepower it becomes necessary to handle the increased current by contactors. The contactor controller with the resistance bank is normally fitted below deck, while the watertight master controller, which deals with the contactor coil circuits only, is fitted above deck in the most suitable position.

Automatic timing and quick reversal prevention by electrical means can be provided, thus the time intervals for cutting out resistances and reversal become independent of the operator.

A "try-out" switch is a usual refinement for this type of control and provides a means of testing the equipment for rotation. Fig. 11 shows the typical characteristic required for this type of control.

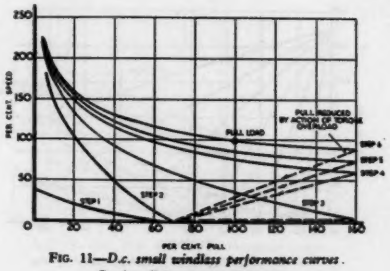


FIG. 11—*D.c. small windlass performance curves.* Gearing efficiency assumed constant.

A.C. Motors and Control Gear for Speed Selection

The severe torque requirements of turning gear coupled with the desirability of providing a crawl speed for engine adjustment makes this a rather difficult drive for a.c. motors. The torque could be provided by fitting a somewhat larger motor, although this is bound to increase the cost and if the crawl speed can be dispensed with then a "Trislot" type motor, possibly fitted with two or four pole-change windings might suffice.

Where a crawl speed is considered necessary then a slip-ring motor with rotor resistance must be provided but here again a rather larger frame may be necessary to obtain the torque requirements.

A third alternative, and one used on some British a.c. ships, is to fit d.c. motors, supplied in this case from a d.c. lighting installation, and as the turning gear is unlikely, or not usually, needed at sea this arrangement has something to commend it.

The requirements of an anchor windlass have already been set out in the d.c. section and the type of a.c. motor most suitable to fulfil the stalling requirements for small and medium size installations is undoubtedly the slip-ring with rotor resistance.

Squirrel-cage motors have been used in the United States, but these have invariably been connected to their loads through variable speed hydraulic trans-

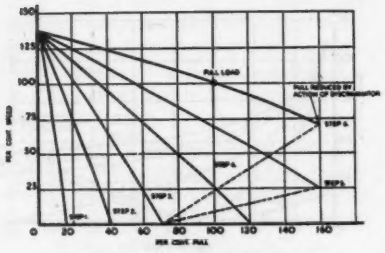


FIG. 12—*A.c. small windlass performance curves*
Gearing efficiency assumed constant.

mission. This is not a method favored here, where it is preferred to obtain the complete characteristic electrically.

Fig. 12 sets out the characteristic obtained from a slip-ring installation and by comparison with Fig. 11 (the d.c. equivalent) it will be seen that a very similar performance can be given, retaining the essential features of torque reduction on overloads, with ready stalling while still maintaining a live pull, and obtaining a reasonable light load speed.

Capstan A.C. and D.C.

The speed load characteristics on an after capstan are essentially the same as the forward anchor windlass and it becomes possible in most instances to fit a similar equipment.

GROUP C—SPECIAL PURPOSE MOTORS AND CONTROL GEAR FOR A.C. AND D.C.

Large Windlasses and Capstans—D.C.

The essential characteristics required in a windlass drive have already been discussed, and the methods of obtaining them, using series control, reviewed. These are satisfactory on small and medium size vessels but with large installations the power which would have to be dissipated in the series resistance makes this control uneconomical, and other methods must be considered.

Some form of variable voltage is needed and there are three methods of obtaining this, viz., Ward-Leonard, motor-reducer and motor-booster. Of the three, after taking into account weight, cost and efficiency the author prefers the motor-booster.

The electrical equipment consists of a motor-booster set with associated starter running off the ship's supply; a main motor fitted with a brake and slipping clutch, contactor panel, and master controller giving steps of control in each direction, successive steps giving increasing speed and torque.

The booster and main motor armatures are connected in series across the supply, and speed control of the main motor is obtained by field regulation of the booster which varies its voltage, not only from zero to maximum, but in either direction as well. This booster voltage subtracts from, or adds to, the supply voltage, automatically giving a speed depending upon the load and step. Thus the voltage across the main motor armature varies from practically zero to twice the supply, giving a falling speed-torque characteristic on all steps as the load increases, the motor ultimately stalling but maintaining a "live" pull. This, in addition to giving the most suitable operating conditions, gives, in conjunction with the slipping clutch, the maximum protection to the cable.

The control obtained is similar to that of the Ward-Leonard system, but it has the advantage that never more than about half the power has to be transformed in the motor-booster set, and at some speeds considerably less, so that in addition to a smaller and lighter set a higher overall efficiency is obtained.

The slipping clutch, fitted internally to the motor armature, reduces the shock of sudden overloads.

A feature of the control is that if rapid switching is necessary in an emergency, this can be effected without causing dangerous surges, as the natural lag in field strength changes tends to smooth out jerks.

Fig. 13 shows the typical characteristic of a windlass with booster control.

Large Windlasses and Capstans—A.C.

Fig. 14 shows a typical characteristic of a large a.c. windlass, this installation being on the "Speedmaster" principle.

Controlled speed steps are obtainable and the actual point of torque reduction can be suited to the drive as also the amount of torque maintained by the equipment in the stalled condition.

The "Speedmaster" is based on the variable frequency principle but utilizes two machines only, the conversion unit and the actual motor.

The conversion unit consists of a variable frequency and variable voltage converter based on the "N-S" motor and requiring only a static induction regulator or transformer. The converter has a commutator and three or six slip-rings which are connected to tappings of the same rotor winding in such a way as to produce a three-phase variable frequency, variable voltage a.c. system. Current is collected from these slip-rings and fed to the variable speed squirrel-cage induction motor. The unit is controlled by the induction regulator or by tap changing of the transformer.

It will be appreciated then that with this system power is not wasted in resistances as with a slip-ring motor, and light load speeds are readily obtainable, varying between standstill and maximum, depending on the position of the speed-regulating induction regulator. The inherently drooping characteristic is very suitable for this class of drive as it enables the equipment to stall readily on overloads.

Winches

The "all-electric" cargo winch is now so firmly established and accepted as the best means of cargo handling, that it needs no introduction.

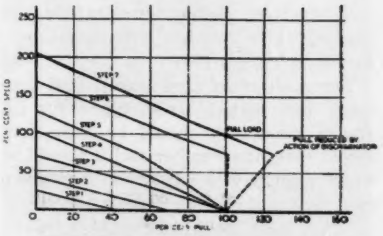


FIG. 13—*D.c. large windlass performance curves*
Gearing efficiency assumed constant.

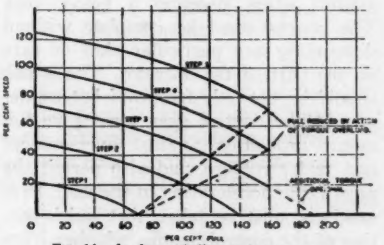


FIG. 14—*A.c. large windlass performance curves*
Gearing efficiency assumed constant.

Broadly speaking the designs can be divided under two headings:—

(1) Mechanically controlled lowering.

(2) Electrically controlled lowering.

Under the first heading there are the winches with series control.

Under the second, winches employing some form of dynamic control, using either series or shunt wound motors.

If mainly series wound motors are employed, then potentiometer control is used involving separate excitation of the series winding and so giving a shunt characteristic. If the motor is mainly shunt wound, regenerative control is available by controlling the field strength.

Mainly shunt wound motors can be used either direct on the line or supplied at variable voltage on the Ward-Leonard, reducer or booster systems.

The above designs are briefly described below and approximate performance curves given.

Some electrical and mechanical features are common to all types, for instance the winch should be fully protected from the weather and it should be fitted with a winding barrel and warp ends best suited to the requirements.

The winch should be capable of picking up and setting down cargo gently, and must give the operator complete control when lowering a heavy load. The control must be complete without demanding any particular skill or care on the part of the operator. The winch should be not only foolproof but rogue-proof. The control gear must give full motor protection against over-current and under-voltage, and also permit the most rapid acceleration of the load. Precautions must be taken that quick motion of the control handle, whether from step to step or complete reversal will not stop the winch. Sufficient steps of speed control should be provided to give a reasonable range from crawl to full speed.

The master controller providing the speed control should be mounted in the most accessible position for the operator. Remote control may be preferred and the master controller can then conveniently take the form of a deck mounting pedestal.

The position chosen for fixing this should enable the operator to obtain the best view of both the hold and dock-side.

Control gear can be fixed either in the winch bedplate or in a deck house. The former gives the advantage of a self-contained winch, but the latter allows maintenance to be undertaken during the voyage irrespective of the weather conditions.

D.C. Series Control. This is a basic design of cargo winch and suitable for use on ships ranging in size from the smallest coaster to the largest liner. The brakes include electrically operated holding, foot, and automatic overspeed. The magnetically operated brake can be considered the stopping brake and it is applied every time the controller is turned to the "off" position or the supply fails. The foot operated brake should enable a slow creep speed to be obtained either lifting or lowering on any control step. The centrifugal brake is a mechanical means of preventing excessive lowering speeds. It should be set at the maximum safe lowering speed which it is then impossible to exceed. Thus it enables heavy loads to be lowered by gravity at maximum speed with the assurance that the safe speed cannot be exceeded.

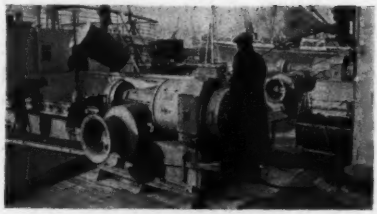


FIG. 15.—D. C. 5-ton cargo winch—basic design.

It is usual to arrange the control gear to give, on the last step only, automatic acceleration with light loads to take advantage of the motor power available.

Fig. 15 shows a d.c. 5-ton cargo winch.

Fig. 16 illustrates the typical performance of this type of winch, the automatic feature being referred to as the "load discriminator."

D.C. Auto-dynamic Control. As the name implies, with this winch, the control system automatically selects the most suitable speed for the load when the controller is on the full-on step in both the hoisting and lowering directions. The lighter the load the faster the speed obtained. This control is obtained electrically in the lowering as well as in the hoisting direction without the use of any form of mechanical brake, by the use of discriminators which automatically select the most suitable speed.

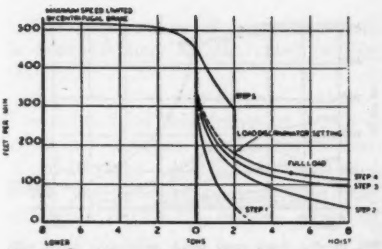


FIG. 16—*D.c. 5-ton cargo winch standard performance curves for basic design*

When lowering, any desired speed less than the maximum is obtainable either by the use of the handbrake release when lowering by gravity or by use of the footbrake when lowering under power. Any desired speed below step 1 is obtainable by use of the footbrake.

The only brake necessary with this form of control is the electrically operated holding brake, the foot and overspeed brakes being dispensed with.

Fig. 17 shows a d.c. 5-ton cargo winch with auto-dynamic control.

This system is ideal for remote control as no mechanical connection is required between the control position and the winch. The performance characteristics of this winch are illustrated in Fig. 18.

D.C. Ward-Leonard Control. The control is by the Ward-Leonard system, in which a small motor generator set, driven by a d.c. motor and housed in a winch bedplate supplies power to the winch motor.

The control gear which is comparatively simple can be housed in the bedplate to be accessible readily and easily removable. A main circuit breaking contactor should be fitted together with the usual protective features. The speed selection is obtained by generator shunt circuit control, no main circuit being made or broken during the working of the winch.

The Ward-Leonard system gives a winch of outstandingly high performance as is shown by the typical curve

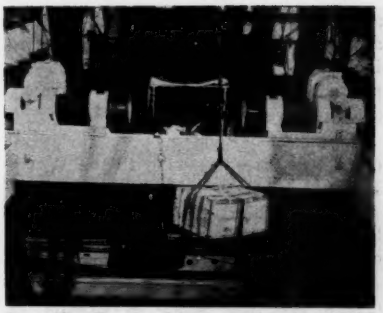


FIG. 17.—D. C. 5-ton cargo winch with auto-dynamic control.

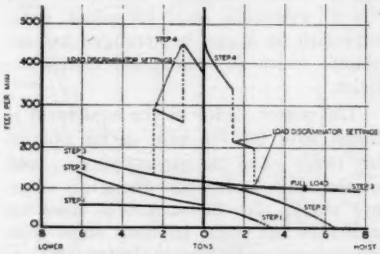


FIG. 18—*D.c. 5-ton cargo winch standard performance curves with auto-dynamic control*

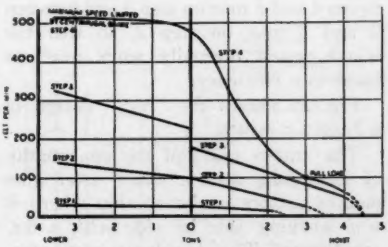


FIG. 19—*D.c. or a.c. 3-ton cargo winch performance curves with Ward-Leonard control*

Fig. 19. As the control is essentially by voltage variation very fine crawl speed control can be obtained electrically without the use of mechanical brakes.

D.C. Motor-reducer Control. Motor-reducer control has been developed from a modification of the Ward-Leonard system and permits the use of smaller

and cheaper machines but with the disadvantage that the control gear has to include a main current reverser. In practice however the control is perfectly satisfactory.

To all intents and purposes the speed control is the same as with the Ward-Leonard system and again very fine crawl speeds can be obtained without the use of brakes. The performance curves in Fig. 20 illustrates this feature.

A.C. Basic Design. Basic mechanical design for this winch is exactly as described under "D.C. Series Control." Electrically it uses the "N-S" variable speed motor already described. The "N-S" system is ideal for winch duty, especially as it can be arranged to give shunt, series or compound characteristics.

The power factor of the equipment is high (over 0.8 for most of the operating range) and the current surges, both at the start and when changing steps, are small. No resistance is used on either of the main hoisting steps with consequent reduction in losses and increase in efficiency. The maximum efficiency of the 5-ton winch occurs between 4 and 5 tons on step 3 and between 2 and 3 tons on step 2, so that the winch would normally work near its maximum efficiency.

Fig. 21 shows the "N-S" design of a 5-ton a.c. winch.

The author has had the opportunity of examining such a winch after nine months service on board ship where it was working side by side with a d.c. counterpart. The stevedores were completely unaware of any difference in the winches.

Fig. 22 illustrates the typical performance for a winch of this design.

A.C. Auto-dynamic Control. The system described under "D.C. Auto-dynamic" can also be applied to this a.c. counterpart, the main difference being that slightly lower light load maximum speeds are obtained, approximately in the ratio of 450-375 ft. per min.

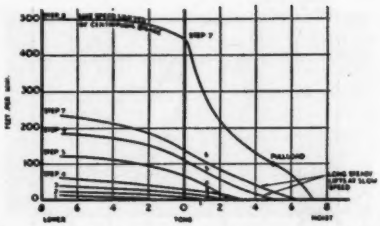


FIG. 20—*D.c. 5-ton cargo winch performance curves with motor-reducer control*

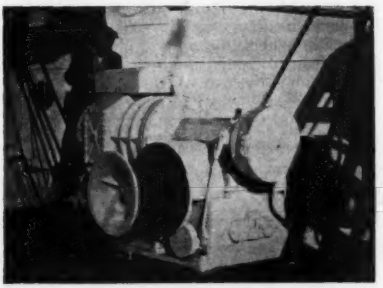


FIG. 21.—A. C. 5-ton cargo winch "N-S" design.

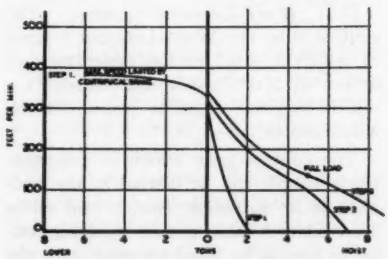


FIG. 22—*A.c. 5-ton cargo winch—"N-S" design*

Lowering any desired speed less than the maximum is obtainable either by the use of the handbrake release when lowering by gravity or by use of the footbrake when lowering under power.

Any desired speed below step 1 is obtainable by use of the footbrake.

The performance characteristics will be approximately as illustrated in Fig. 18.

A.C. Ward-Leonard or Converter. The control for this design of winch is as described under the d.c. winch with Ward-Leonard control, of which this forms the a.c. counterpart. The only difference is that the driving motor of the generator set is a.c.

The performance will be the same as for the d.c. winch Fig. 19.

Fig. 23 shows a d.c. or a.c. 3-ton cargo winch.

Heavy Duty Winches. Spur gearing and heavy duty drums can be employed in conjunction with the foregoing types to enable direct lift of up to 10 tons to be made at about half speed. These drums can be permanently geared or, when only occasional lifts are required, the gears can be engaged by means of a hand lever.

Warping Winches. Winches with extended shafts and warp ends are normally supplied for warping duty. Fine speed control is usually unnecessary with this type of winch. A torque overload device should be incorporated to provide protection to the cable in the event of overloads, by enabling the winch to stall but still maintain a live pull. Speed should be automatically increased as the overload decreases. Fig. 24 illustrates the typical performance of a d.c. winch. A similar control can be offered for a.c. operation (see performance curve Fig. 12).

Steering Gear

Many gears of both the Ward-Leonard and single-motor type have been supplied since the first all-electric steering for the *M.S. Mississippi* was supplied in 1913. These have invariably shown exceptional reliability. From time to time improvements and modifications of design giving greater simplicity of working have been introduced, so that at the present day electric steering gear may be relied upon to give service unsurpassed in reliability.

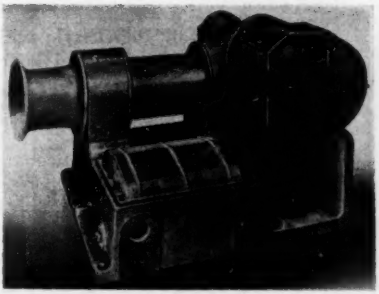


FIG. 23.—D. C. or A. C. 3-ton cargo winch with Ward-Leonard or converter control.

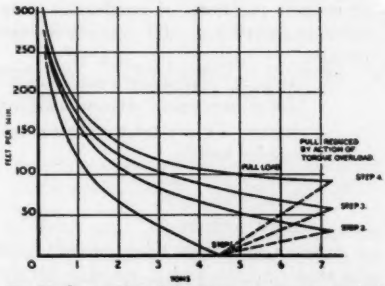


FIG. 24—*D.c. warping winch performance curves for standard design*

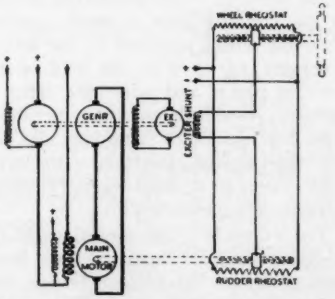


FIG. 25—*Diagram of connexions for Ward-Leonard system of steering gear*

The main differences in electric steering gears are in the supply and control of current to the rudder motor, and the four types may be defined as:—

(1) Ward-Leonard all-electric.

(2) Electro-hydraulic.
(3) "Push-pull" all-electric with mechanically operated hunting gear.
(4) "Multi-core" all-electric with rudder follower.

Ward-Leonard. The Ward-Leonard system gives probably the most perfect method of steering gear control and has been supplied to a number of large vessels including those of Union Castle, Port Line and Blue Star.

It gives very fine steering and the driving motor is designed to start against the very high torques required at certain positions of rudder, in some cases amounting to 400 percent normal torque.

The complete equipment comprises:—
Motor-generator set and exciter.
Starter for motor-generator set.
Rudder motor.
Bridge rheostat.
Rudder rheostat.
Limit switches.

A motor-generator takes current from the ship's mains, and is running all the time at sea. The generator end of this set supplies current at a varying voltage to the steering motor connected directly to the steering gear through gearing. Thus the power required by the motor-generator varies with the load on the steering motor and when the latter is standing, very little current is needed to keep the generator running idle. To give the varying excitation of the generator there is a small exciter coupled to the motor-generator.

The control is by operation of the bridge and rudder rheostats, these being connected as a Wheatstone bridge, supplying the exciter shunt. The rudder rheostat being one leg of the Wheatstone bridge and the bridge rheostat the other.

With both rudder and bridge rheostats in coincidence the exciter shunt is dead, but when the steering wheel is moved, operating the bridge rheostat, coincidence is upset and the exciter shunt is energized. This in turn, excites the generator shunt and current is supplied to the rudder motor. This turns the rudder, at the same time driving the rudder rheostat until coincidence is reached, when the generator is again at zero volts and so the main motor stops.

An advantage of some consequence with this system is that it may be applied equally well to a.c. or d.c. ships, without affecting the performance. The only difference being in the type of motor for driving the generating set.

With this system there is no making and breaking of contacts in the generator local circuit with sparking and burning of tips; the control is such that the voltage on the motor gradually builds up to provide the necessary torque, and dies down as the rudder reaches the required position, giving a very smooth action. Owing to this absence of electrical and mechanical shock, wear and tear are reduced to a minimum.

Electro - hydraulic. The Electro - hydraulic system depends upon a constant speed motor driving an oil pump. This type of equipment can be designed for all sizes of vessels from the smallest to the largest, and is very reliable. Starting and stopping considerations are eliminated as the motor runs continuously during the voyage. As with the Ward-Leonard equipment, this type is again equally suitable for a.c. ships, as the motor starts under light load conditions and is not called upon for unduly heavy overloads. A motor of the "Trislot" type designed to match the characteristics of the oil pump is eminently suitable.

Push-pull System. This is an all-electric single motor equipment essentially d.c. and designed especially for smaller vessels such as coasters. The equipment comprises:—
Rudder motor.
Reversing contactor starter.
Drum type master switch.
Limit switches.

Movement of the wheel starts the

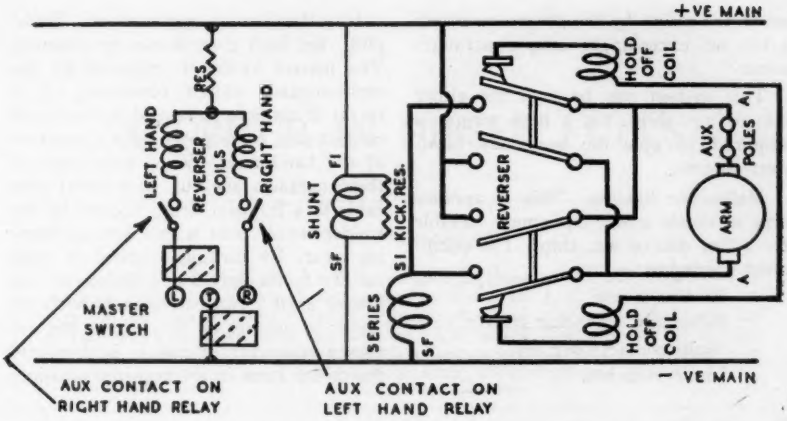


FIG. 26—*Diagram of connexions for "Push-pull" system of steering gear*

motor via a master switch and the contactor starter. The rudder follows until its hunting gear returns the master switch to the "off" position, stopping the motor. The rudder is then in coincidence with the position of the wheel. Further movement of the wheel again results in a similar sequence of operations.

With some small gears, such as are fitted to small yachts, trawlers, etc., the motor is designed to be switched direct

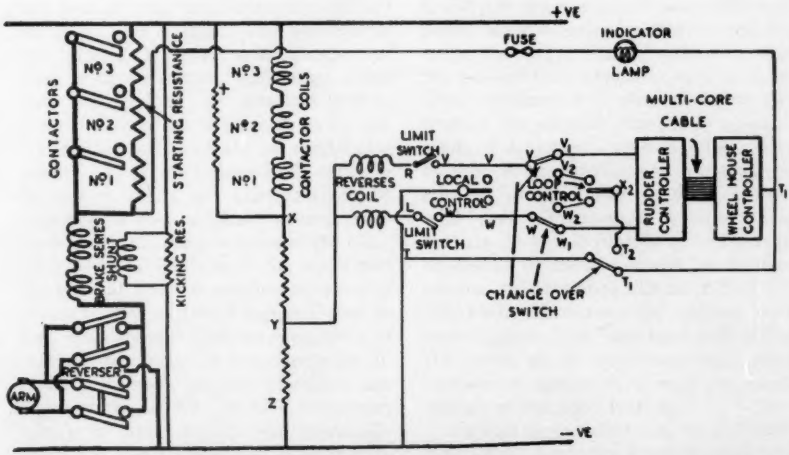


FIG. 27—*Diagram of connexions for multi-core system of steering gear*

on to the mains by the reversers, which gives an exceedingly simple arrangement.

This system can be used for either d.c. or a.c. ships, but a high torque is required to give the necessary hard-over torque.

Multi-core System. This is another type of single motor equipment suitable for either d.c. or a.c. ships. The equipment comprises:—

Rudder motor.
Reversing contactor starter.
Multi-contact switches.
Limit switches.

It is similar in operation to "Push-pull," but finer control can be obtained. The master switch is replaced by the multi-contact switch consisting of a spiral of contacts arranged so that each contact can correspond with a position of the handwheel. Wires from each of these contacts are run in a multi-wire cable to a follower drum rotated by the rudder motor, and which acts as hunting gear. By turning a spiral of gaps similar to the spiral of contacts on the bridge until a gap corresponds with the finger in contact on the bridge, the reverser contactor circuit is broken and the motor stops in the required position.

CONCLUSION

From the foregoing it will be seen that it is possible to supply a.c. machines with approximately the same characteristics as d.c. In every case it is to be hoped that ships' engineers will approach the problem with the main idea that only electrics designed for marine duties should be used on board ship.

SULPHUR IN DIESEL FUELS

ACKNOWLEDGMENT

The 1948-49 proceedings of the Automobile Division of the Institution of Mechanical Engineers contained this article by PROF. IR. J. J. BROEZE and MR. A. WILSON. It discusses some of the undesirable effects of sulphur in diesel fuels, and precautionary measures that can be taken. The article indicates that by suitable design, operation, and lubrication, the diesel engine can be made to consume fuels of a higher sulphur content than has been usual, without adverse results.

INTRODUCTION

In the petroleum industry outside the United States, the near future is largely dominated by the projected exploitation of enormous oil reserves in the Middle East areas. Given a period of time without strife, these reserves will serve very materially in helping the return to prosperity of a large part of the Old World, and both directly and indirectly will aid the New. The influx of vast amounts of new crudes, however, will tax the resources of petroleum technology since each new find of raw material usually poses its own special problems in the preparation of products of marketable quality. Thus the crudes from many of these new fields are characterized by relatively higher sulphur contents than those predominating in some of the older established oil fields, with the result that the general level of sulphur contents of products such as Diesel fuel will tend to rise. This trend is likely to continue over the next few years so that supply conditions, previously peculiar to only a few areas of the world (or of a temporary nature in other areas), will eventually prevail in many territories including the United Kingdom and European countries generally.

It is this trend that has focused a good deal of attention recently upon the significance of the sulphur which forms an integral component of Diesel fuels as of many other petroleum products. It is not that the Diesel engine has something entirely new to encounter, but what has regularly been used by relatively few engines in the past—although tasted spasmodically by others—will become the staple diet of the many. In the case of fuels normally used in large Diesel engines, it is generally agreed to restrict the sulphur content to a maximum of 2 percent, while distillate fuels as used in the smaller and higher-speed engines usually have sulphur contents well below 1.5 percent. It is not expected that the fuels will have sulphur contents in excess of those allowed by modern general specifications like the B.S.S. No. 209:1947. However, the sulphur contents in most cases have been well within the limits set, so that users have come to have an optimistic idea of the implications of the specification.

As with any modification of fuel characteristics, naturally some engines will reveal a greater sensitivity to the overall increase of sulphur than others. It

may also be that weak points in operation and maintenance will be accentuated to the point of recognition. In this paper a brief assessment of the problem presented by these circumstances is attempted with the object of enabling engine designers and users to anticipate the difficulties and to suggest action which might be taken to meet the situation.

The first open intimation that sulphur in the fuel might play a part in processes leading to engine deterioration was in Ricardo's 1933 lecture* on cylinder wear, when the theory that wear was largely a question of corrosion was advanced. Up to that time it had been the firm belief based on textbook chemistry that sulphur burns to sulphur dioxide and that only at relatively low temperatures could condensation of the water vapor formed in the combustion process occur. Working with petrol engines, Williams in 1934 established that the presence of relatively small proportions of sulphur in the fuel had most detrimental effects upon cylinder wear and concluded that this was due to acid-bearing moisture condensing upon the cylinder walls at low temperatures.

The authors' own contacts with engines in service had led them to recognize sulphur as an active wear agent, and investigations on cylinder wear proceeded at Delft utilizing, amongst others, the wear measuring method described by Boerlage and Gravesteyn (1932) of collecting and ashing the used cylinder oil to estimate the wear products. This method proved eminently successful in that it facilitated measurement of wear over relatively short periods and enabled a wide range of fuels to be compared. It was stated (Broeze and Gravesteyn 1938) that sulphur contents particularly of 1 percent and over contributed markedly to cylinder wear, and that, contrary to common belief, some part of the sulphur burned in the engine to sulphur trioxide.

Cloud and Blackwood (1943), experimenting with three different types of automotive Diesel engine, reported that 60–90 percent of the sulphur burned to SO_3. They carried out engine tests which pointed to the fact that SO_2 had little deleterious action compared with SO_3, and found that the latter gave rise to heavy wear and the formation of resinous materials, which at the high temperatures incident to engine operation hardened to produce varnish and coke. Wear was attributed to acidic corrosion and abrasion by hard carbon. Since the war several technical papers have appeared on the subject and a substantial amount of evidence has been collecting confirming the deleterious effects of sulphur (Miller and Nelson 1947, Moore and Kent 1947, and Blanc 1948).

During these years the Royal Dutch-Shell Group Laboratories have been continuing an intensive research on the sulphur problem from the aspects firstly, of removing the sulphur from the fuel and secondly, of studying the mechanism of the action of sulphur in the engine with the object of developing methods to counteract the deleterious effects.

Technically, the problem of removing the sulphur has been solved. The problem is involved in that relatively small percentages of sulphur are chemically combined with large amounts of hydrocarbon structures in the form of complex molecules. In some cases these molecules behave in a sufficiently specific manner to permit their removal by solvents or chemical agents. However, this method of treatment is not particularly attractive, partly on account of the fact that some sulphur-containing molecules of certain crudes cannot be extracted, but mainly because this process involves removing not only the sulphur but the whole molecules with which the sulphur is combined. In consequence there is a very appreciable loss in the treatment and large quantities of highly sulphurous extracts are obtained for

*An alphabetical list of references is given in the Appendix, p. 1004.

which there is no commercial use. The more feasible method is a process of hydrogenation in which the sulphur atom in the molecules is directly attacked and replaced by hydrogen. The losses involved are correspondingly reduced and products extremely low in sulphur are produced. Unfortunately this process cannot be carried out as part of the processing in existing plant. It necessitates an entirely new step in refining the fuel, requiring completely new plant for this stage of the treatment. Quite apart from the economic aspect, the present demand for increased production of petroleum products, requiring the construction of extensive new refining plant, storage, and transport facilities, makes the introduction of such a process practically impossible, at least for several years to come. It becomes necessary to assess the seriousness of the problem, therefore, and to give consideration to other potential solutions.

PHYSICAL AND CHEMICAL REACTIONS OF SULPHUR IN THE ENGINE

That SO_3 is formed in the combustion process is quite certain, although it is questionable whether the amount is as great as has been reported. Analysis of the exhaust gases reveals the presence of SO_3, but estimates of the actual percentage are largely dependent upon the point, rate, and method of sampling, as well as upon the method of analysis. Conversion of the lower into the higher oxide, which may be influenced by surface catalytic effects, can and does occur between the combustion chamber and the point of examination. It seems likely that these surface catalytic effects may also operate where they are least wanted, that is on the cylinder wall, so that the actual determination of the SO_3 in the combustion space itself, let alone in the exhaust line, would be of limited value.

The formation of SO_3 in the combustion process, even in small amounts, has a profound effect upon condensation within the cylinder. At first sight, the possibility of condensation of aqueous acid products within the cylinder of an engine under normal working conditions might seem remote. Further consideration, however, shows that it is entirely possible. Very small proportions of SO_3 raise the dew-point considerably, a fact which was first emphasized by Johnstone (1929) and is now widely recognized as a leading factor promoting corrosion in combustion plant generally. In particular regard to engines, consider a cylinder containing gas at a pressure of 35 atmospheres with the cylinder wall maintained at 160 deg. C. If part of the gas is replaced by water vapor no condensation will occur until steam is present in sufficient quantity to exert a partial pressure of 6 atmospheres, this being the saturated vapor pressure of water at the wall temperature. If the quantity of steam is less than this amount it will simply superheat and no condensation will occur.

Now consider the case when steam is added only in sufficient amount to produce a partial pressure of ¼ atmosphere, which, in fact, is considerably less than that actually present in an engine cylinder under these pressure conditions on the expansion stroke. The system is far removed from the point of condensation. However, if a minute quantity of pure sulphuric acid is introduced, sufficient to produce vapor concentration of little more than one part per million by volume, then condensation of, for example, an 80 percent sulphuric acid solution can take place. Condensation of acid films on the cylinder bore is thus entirely feasible (Johnstone 1929, Taylor 1942, and Hoegh 1942). Obviously the quantities required to produce these partial pressures are a minimum when the volume in which the vapors are dispersed is likewise at a minimum, and hence

conditions are worse near top dead center.

Direct evidence of condensation has in fact been obtained by inserting a probe, comprised of copper and zinc electrodes separated by mica, into the combustion chamber of an engine. Condensation of sulphuric acid bridging the gap between the two metals produces a small Daniell-type cell. When there is only a thin film of condensate on the probe, the internal resistance of the cell is high, producing a low current. As the amount of condensate increases the internal resistance is reduced and the current increases correspondingly. The probe therefore gives some measure of the amount of condensation, the form of a typical cathode-ray trace being shown in Fig. 2. Again, occasionally on the crowns of pistons withdrawn from the engine vigorous localized reactions have been observed to commence after standing for some time. Examination has revealed a minute globule of sulphuric acid trapped in a small pocket of lacquer or carbonaceous material which has broken down and allowed the acid to come into contact with the metal. A similar effect is often responsible for the flaking, owing to corrosion of the surface layer of metal beneath the film, of coherent lacquer films on pistons which have been allowed to stand for some time. Investigation reveals the presence of the metal sulphate on the surface.

Hitherto, condensation effects only have been considered. The action of sulphur, however, is not limited to this aspect. Other reactions occur which have considerable influence, even under high-temperature conditions. Thus, the presence of sulphur oxides in the combustion chamber appears to have marked effects upon the polymerization reactions of partially oxidized hydrocarbons, leading to the formation of lacquer and ultimately carbon. The nature of the residual carbon or soot from the combustion process is greatly modified by sulphur towards greater density and hardness. Moreover, interaction between sulphur products and the lubricating oil film seems likely.

The effect of sulphur on lacquer formation has been shown by the deposition on a "Pyrex" window in communication with the combustion chamber. With the arrangement used, over relatively short periods (less than one hour) it was found that lacquer without any trace of carbonaceous material gradu-

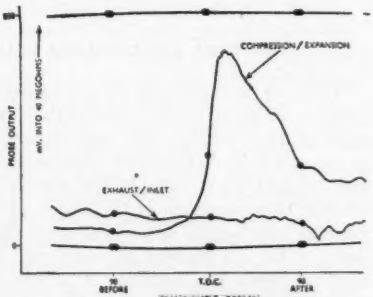


Fig. 2. Output from Voltaic Cell Probe in Combustion Chamber of Compression-ignition Engine

ally built up on the inner surface of the window. Running under identical conditions over a fixed period on fuels of different sulphur contents, the amount of window fouling was measured by determination of its optical density. The effect of sulphur content is shown in Fig. 4. It is apparent that increase of sulphur content of a naturally occurring form increases lacquer deposition on the window, and the same tendency modified by temperature effects and the presence of lubricating oil can presumably be anticipated on other internal parts of the engine. The anomalous behavior of certain sulphur-containing compounds such as sulphurized olefins, as shown in Fig. 4 and which was again reflected in wear tests, although an isolated example, casts some doubt on the generally accepted theory that the form of the sulphur in the fuel has no influ-

ence on the effects in the engine, and renders somewhat questionable the experimental technique of adding sulphur-containing compounds to achieve variation in sulphur content. The procedure adopted where possible has been to desulphurize a fuel intended for laboratory reference purposes by careful hydrogenation, which has had no apparent effect upon the essential characteristics of the fuel, and to achieve intermediate values of sulphur content by blending.

Examination of the exhaust soot shows that sulphur products are strongly adsorbed to the particles, which has a remarkable effect on the nature of the soot. Running on a fuel containing 1.5 percent sulphur, the exhaust soot is found to contain as much as 9 percent sulphur and the apparent density (or packing volume) is about 0.5 gm. per cu. cm. With an extremely low sulphur fuel (0.08 percent sulphur), the sulphur content of the exhaust soot is only about 1 percent and the apparent density 0.03 gm. per cu. cm. While the latter soot is fluffy and voluminous, the former is hard, dense, and likely to be abrasive.

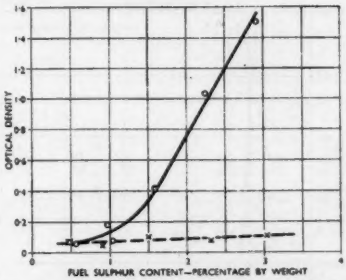


Fig. 4. Effect of Fuel Sulphur Content on Optical Density of Combustion Chamber Window Deposit

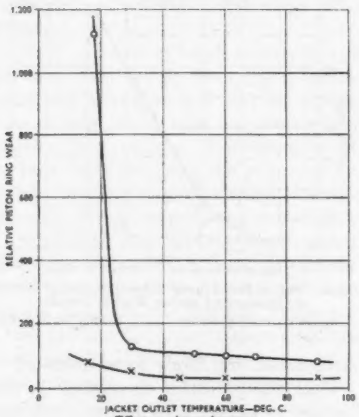
○ Naturally occurring sulphur. × Sulphurized olefins.

Thus the presence of sulphur in the fuel can be expected to lead to condensation of acidic products, particularly when the cylinder walls are cold, to the formation of lacquer, and to hard, abrasive carbonaceous deposits. The condensation effects will be most serious under low-temperature operating conditions, but carbonization is likely to be most severe under high-temperature conditions.

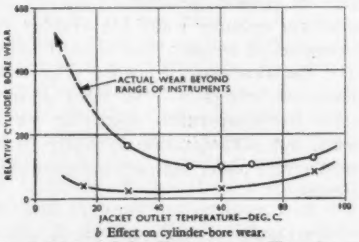
EFFECTS OF SULPHUR ON THE ENGINE

Cylinder Wear. Wear of cylinders and rings has been the subject of much investigation without the factor of sulphur even being mentioned or relevant. Two main causes have been recognized: abrasion and corrosion. Precise separation of abrasive and corrosive wear is difficult, particularly since introduction of the one increases the other, but in considering the mechanism of wear it is convenient to think in terms of these two forms. It is further useful to distinguish between true abrasive wear due to foreign particles in the oil film, dust, hard carbon, and wear particles, and the wear arising from limited but actual metallic contact between the opposing surfaces due to breakdown of hydrodynamic lubrication. In the latter case local "pick-up" of metal occurs from one surface to the other; it is, in fact, a mild form of scuffing and might be described as attritious wear. This type of wear is considered most important and has possibly not always received due attention. Attrition is likely to be most serious at the upper end of the ring travel on the firing stroke when the top compression ring is carrying practically the full gas pressure and lubrication conditions are far from perfect. For reasons discussed in the previous section, corrosive wear is also greatest at the top of the stroke, while owing to the debris of wear products abrasion too tends to be aggravated.

On the basis of work carried out in the research laboratories of the Shell Development Company, California, Cattaneo and Starkman (1948) have expressed the opinion that in certain circumstances the rate of corrosive wear



a Effect on piston-ring wear.



b Effect on cylinder-bore wear.

Fig. 5. Effect of Jacket Temperature on Piston-ring and Cylinder-bore Wear with Fuels of Different Sulphur Content
○ 1·5 per cent sulphur fuel.
× 0·08 per cent sulphur fuel (desulphurized 1·5 per cent sulphur fuel).
Note: Wear on 1·5 per cent sulphur fuel at 60 deg. C. taken as 100. B.m.e.p. 70 lb. per sq. in.

may be reasonably constant but mechanical wear varies in somewhat haphazard fashion, causing a variation in the proportions between the two.

That sulphur greatly aggravates the wear problem is unfortunately an undeniable fact. In view of the circumstances outlined in the previous section this is not surprising. It seems certain that the deposition of sulphuric acid can and does occur on the cylinder walls and naturally greatly accentuates the amount of corrosion and consequent wear. For reasons discussed in the preceding section, it is to be anticipated that the surface temperature of the cylinder bore will be a critical factor, and this has been borne out experimentally. Wear was studied

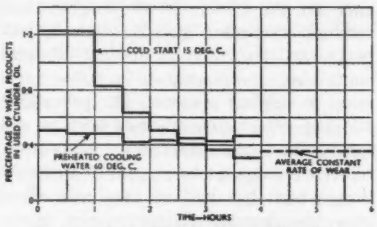

PERCENTAGE OF WEAR PRODUCTS IN USED CYLINDER OIL
COLD START 15 DEG. C.
PREHEATED COOLING WATER 60 DEG. C.
AVERAGE CONSTANT RATE OF WEAR
TIME—HOURS

Fig. 6. The Effect of Cold Starting on Cylinder Wear

as a function of engine coolant temperature employing both relatively high and extremely low sulphur fuels (respectively 1.5 and 0.08 percent sulphur, the low sulphur fuel being produced from the higher sulphur fuel by a process of desulphurization).

The data for a particular engine and certain load conditions are presented in Fig. 5a and b. Engine design has considerable bearing on the matter and the data given must be regarded as illustrative only, but strikingly illustrative in view of the fact that at average jacket temperatures with the higher sulphur fuel, bore wear is about doubled and ring wear about trebled, relatively to the lower sulphur fuel, and that these ratios are very much greater when jacket temperature is reduced. While the data have been given in terms of the coolant temperatures, the critical temperatures, of course, are those of the inner skin of the cylinder liner. Corresponding coolant and wall temperatures are given in Table 1.

Although most engines do not normally operate at temperatures at which the heavy wear takes place, many engines are allowed to operate at too low a jacket temperature. Further, in starting from cold all engines encounter these temperatures and so run for a period under heavy-wear conditions. The duration of this period has considerable effect on the total wear of the engine. The effects of starting wear are illustrated in Fig. 6.

In another series of tests to study starting wear, an engine was run on

TABLE 1. RELATIONSHIP BETWEEN COOLANT AND CYLINDER-WALL TEMPERATURES

	Jacket outlet temperature, deg. C.											
	20				50				80			
Axial location of thermo-junctions	Temperatures measured by thermo-junctions located 0·015 inch beneath cylinder-bore surface, deg. C.											
Top dead centre position of top ring	84	105	85	109	108	125	104	126	132	149	123	148
Mid-position of top ring	50	56	52	52	73	78	74	72	96	102	97	101
Bottom dead centre position of top ring	57	58	54	56	78	79	76	76	99	102	98	99
Peripheral positions of thermo-junctions	Thrust side	Flywheel end	Non-thrust side	Timing end	Thrust side	Flywheel end	Non-thrust side	Timing end	Thrust side	Flywheel end	Non-thrust side	Timing end

fuels of widely different sulphur content with warm and cold starts, so that every combination occurred. The engine was run on a particular fuel, and after standing overnight, was started next morning either from cold or with warmed jackets on one or other of the fuels. The results are shown in Table 2, which gives the total amount of wear products extracted from the used cylinder oil over the first few hours of running. It is seen that the engine "remembers" what it has experienced the day before, but that it is nevertheless possible to suppress the hangover by exercising due care in the morning.

Large low-speed engines appear to be somewhat less prone to cylinder wear from sulphur in a fuel than the small high-speed units, which might be expected. Mean effective pressure, fuel/air ratio and, hence, flame temperatures all are practically the same, but heat transfer is slightly less in large engines owing to lower gas movement, and the temperature drop across the liner walls is appreciably higher because the walls are so much thicker. In consequence the large engines have higher internal skin temperatures with correspondingly reduced danger of condensation. Also, for an equal rate of wear, the large engine can stand more loss, and hence may operate longer without undue ill effects. However, even if the danger of condensation is thus reduced, lubricating conditions are sometimes aggravated by the high temperature and, in fact, it is

TABLE 2. CYLINDER WEAR IN RELATION TO SHUT-DOWN AND STARTING CONDITIONS

	Wear in grammes following a warm start (60 deg. C. cooling water) after standing overnight and being shut down on:		Wear in grammes following a cold start (15 deg. C. cooling water) after standing overnight and being shut down on:	
	0·2 per cent sulphur fuel	3·0 per cent sulphur fuel	0·2 per cent sulphur fuel	3·0 per cent sulphur fuel
Start on 0·2 per cent sulphur fuel	1·2	1·1	1·0	4·7
Start on 3·0 per cent sulphur fuel	1·9	2·3	2·9	4·3 3·0*

* Load gradually increased over 45 minutes instead of over 10 minutes after start.

the high temperatures in large engines which frequently limit their output and may give rise to high rates of wear.

Generally lubricating conditions are better in four-stroke than in two-stroke engines, which is usually reflected in higher wear of the latter. The absence of an idling stroke for oil transport to the cylinder walls, combined with the disturbance in the oil path by the ports, and the higher average gas temperature resulting in higher average surface temperatures, are all contributing factors.

Precise and separate assessment of the different forms of wear is not possible since each affects the other. Examination of the carbonaceous deposits when running on a relatively high sulphur fuel and at high temperatures reveals that they are extremely hard, such that scratching of the cylinder liner is to be expected. The same mechanism which leads to the formation of hard, dense soot found in the exhaust gases and men-

tioned in the previous section presumably gives rise to deposits of this nature. A case of resulting excessive abrasive wear was encountered in a two-stroke auxiliary marine engine. The abnormal and lopsided cylinder wear illustrated in Fig. 7 was definitely traced to heavy abrasion caused by contact between hard top-land carbon and the cylinder. Attack of the lubricating-oil film by sulphur products, also, no doubt, contributes greatly to abrasive wear.

While it is not possible to measure separately the influence of sulphur on corrosive and abrasive wear, the net effect of increasing sulphur content has been estimated and reported (Boerlage and Gravesteyn 1932). Fig. 8 shows the results of comparative tests from which it will be observed that, in general, wear increases almost linearly with sulphur content although there may be some tendency for the curve to flatten out at the lower concentrations.

Fouling. Like wear, engine fouling occurs with completely sulphur-free fuels. Deposits form on the piston and in the combustion chamber, the crankcase oil becomes contaminated and both internal and external fouling of the injector may take place. The amount of fouling in all forms is increased by the presence of sulphur in the fuel, and again the extent of this increase is largely affected by engine design. The effect of sulphur content on crankcase oil fouling and ring-groove deposits is clearly illustrated in Table 3, which, incidentally, refers to an engine characterized by extremely good combustion.

TABLE 3. ENGINE FOULING AS AFFECTED BY SULPHUR CONTENT OF THE FUEL (NON-DETERGENT OILS)

Sulphur content, per cent	Oil-insolubles plus engine deposits in grammes, corrected for ash content	Deposits on rings and in ring-grooves in grammes, not corrected for oil content
0·06	11·4	2·1
0·04*	6·1	2·2
0·85	26·8	8·3
0·85	29·1	5·8
0·85	19·8	3·4
2·9	52·7	9·0
2·9	83·9	12·2
2·9	61·1	8·8

* Town gas was used as fuel.

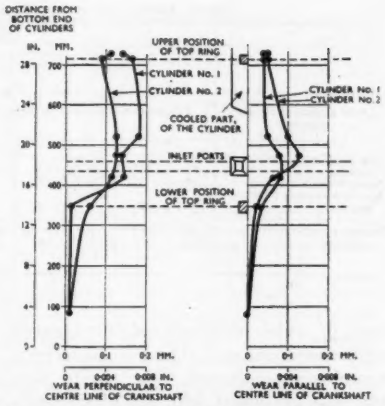


Fig. 7. Bore Wear of Two-cylinder, 120-b.h.p., Medium-speed, Auxiliary Marine Engine, after 1,560 hours of Operation

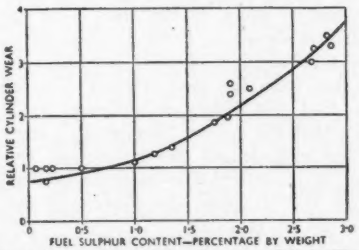


Fig. 8. Effect of Fuel Sulphur Content on Cylinder Wear

In another series of tests with a different engine run on fuels containing 0.2, 0.9, and 1.6 percent sulphur, comparative piston cleaniness ratings of 5.8, 3.9, and 3.3 respectively were obtained, where 10 represents a perfectly clean and 0 a completely lacquered piston according to an arbitrary scale. In the same tests, the low sulphur fuel caused only slight staining of the cylinder bore and no rusting occurred. With the highest sulphur fuel there were appreciable carbonaceous deposits, and marked lacquering and rusting were found after the test. Using the low sulphur fuel no trouble was experienced with the injector, and at the end of the test it was internally clean and no "trumpets" had formed. When running on the highest sulphur fuel internal fouling, partial

blocking of spray holes, and trumpeting occurred, necessitating cleaning several times in the course of the test. In all three tests the valve faces and seats were not greatly different, but in another test on a sulphurous fuel run at lower jacket temperature (30 deg. C. instead of 70 deg. C.) the exhaust-valve seat was heavily carboned and corrosively pitted.

These fouling effects with higher sulphur fuels are to be expected for the reasons outlined in the previous section. It has been noted that sulphur has profound influence on lacquer formation and on the nature of the carbonaceous residues from the combustion process, and these effects are simply reflected in the condition of the engine after running on higher sulphur fuel. Reaction between sulphur oxides and the lubricating oil is not surprising when it is borne in mind that both SO_2 and sulphuric acid are actually used for refining lubricating oils. Combination with unsaturated and oxidized compounds occurs to form an acid sludge, and there is further a strong coagulating effect on dispersed matter. These effects can and do occur in the used oil in an engine, leading to deposits on the piston and the collection of sludge in the crankcase.

In most engines, this acidic sludge will mix with the lubricating oils in the crankcase and render it potentially corrosive. Fortunately corrosion seldom occurs unless there are other contributing causes. Condensation of moisture is one such factor and in marine engines the presence of salt even from the atmosphere may induce corrosion.

MEASURES TO COUNTERACT THE DELETERIOUS ACTION OF SULPHUR

Since experimental evidence points to SO_3 being the more objectionable oxide, SO_2 being relatively innocuous, the most direct approach to the problem would be to prevent the formation of SO_3. Unfortunately the chances of accomplishing this in the combustion process appear to be remote, although combustion which tends to produce soot, to which sulphur compounds are adsorbed, rather than aldehydes, may have some equivalent effect. The alternatives then are to prevent condensation of the SO_3 in the form of sulphuric acid, to neutralize the acid, or to make the surfaces which are subject to attack corrosion-resistant. Means for achieving one or other of these alternatives, at least in part, are discussed in the following paragraphs. At the same time, the aspect of high-temperature wear will be considered.

Engine Design and Operating Conditions. Attention has been drawn to the exceptionally high rate of wear which occurs when wall temperatures are low. Design factors and control of operating conditions to avoid these circumstances will obviously contribute greatly to a reduction of wear. From the engine design aspect, the coolant spaces and flow should be so arranged that excessive cooling of the upper part of the cylinder liner is not encountered during running, and that rapid warm-up of these parts when starting is encouraged. Operating conditions likewise should be controlled to achieve the same effect, however, rapid warm-up should not be attained by increasing load too quickly.

The entry of large quantities of fuel into a cold combustion chamber gives rise to chilling at the walls and consequent incomplete combustion. The unstable oxygen compounds formed are also corrosive, quite apart from the effect of sulphur compounds, and additional wear may occur. This same phenomenon has been encountered in studying preflame reactions and lacquer formation in petrol engines when the gases have simply been subjected to the compression process without being spark ignited. Appallingly severe corrosion has occurred even to the extent of pitting the cylinder head. The increased wear caused by rapidly applying load is shown in Table

2. It follows that rapid warming-up must be achieved without running into these conditions, and this can only be accomplished by appropriate design and control of the cooling arrangements.

The ideal arrangement is to preheat the coolant before starting and the beneficial effects of this are also illustrated in Table 2. However, this is not always possible, but thermostatic control of the circulation achieves practically the same object and is strongly recommended. In large engines manual control of the circulating flow is usually possible and this flow should be restricted until the engine is warm. The old-fashioned but still sometimes-used system of "once through" cooling, the ill effects of which have been experienced by fishing fleets throughout the world, cannot be too strongly condemned.

Such is the position from the low-temperature aspect. In preventing condensation troubles by avoiding low cylinder-liner temperatures, care must be taken not to go to the other extreme. Quite apart from the problem of heat stresses, reference to Fig. 5 and Table 1 indicates that increased cylinder wear is to be expected when skin temperatures in excess of approximately 150 deg. C. are reached. Moreover, under such conditions excessive lacquering and carbon formation can be anticipated and the danger of ring-sticking need hardly be stressed. This matter is of considerable importance in regard to supercharged engines. The increased heat transfer tends to raise the operating temperatures of the top-ring and liner surface which already have proved a limiting factor even in engines of moderate size and speed. Thus increased cooling is called for, which stresses the necessity of measures to prevent over-cooling during periods of low load and warming up.

Before leaving the subject of engine design one further matter should be mentioned. It is desirable that the cylinder wall should not form an essential boundary of the combustion space. As far as possible, from the point of view under consideration, the burning gases should be "contained" by the piston or otherwise, and the cylinder wall shielded from their effects. Experiments have shown that intensive gas movement during the combustion period tends to scour the lubricating-oil film from the cylinder walls, resulting in high oil consumption, while the products of partial combustion are deposited on the walls and lead to excessive sooting of the crankcase oil. In the case of two-stroke engines, penetration of the combustion gases into the scavenge ports causes fouling and, by proper port timing, should be prevented as much as possible. In the vicinity of the exhaust ports, intimate contact between combustion gases and cylinder wall cannot, of course, be avoided and local wear is often experienced.

Considering now the injector, it is imperative to avoid overheating. High nozzle tip temperatures lead to the formation of "trumpets" which interfere with the spray, and overheating of the injector body causes internal lacquering and ultimate malfunctioning. The presence of sulphur in the fuel aggravates both of these troubles. The necessity for keeping the whole injector cool cannot be overstressed.

Metallurgical Protection. Protection of the vulnerable parts by surface treatment or by making them of special alloys offers considerable promise in respect of the wear problem. One such method is that of chromium plating the liner and etching to make it "porous" and capable of retaining an oil film. This process has already found wide commercial application.

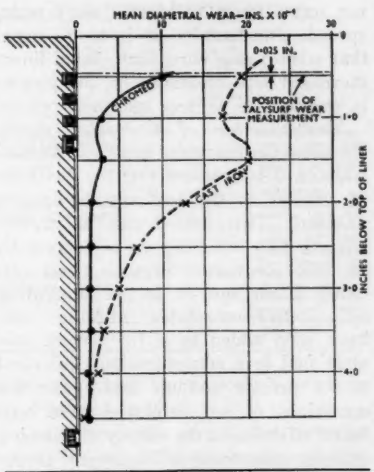
The criticism is sometimes made that chromium plating is simply a temporary expedient, and that once the plating has been penetrated at the upper end of the liner no benefits accrue. This is not actually the case. Since the plating still remains on the lower part of the liner, wear in this region continues to be less with a corresponding reduction in total wear debris, which has a beneficial effect even in respect of the unplated parts of

the liner. Further, owing to the unworn condition of the lower part of the liner, blow-by is reduced, leading to less fouling in the crankcase. Fig. 10 shows the wear profile of a plated and an unplated liner, illustrating particularly the beneficial effect of chromium plating on the lower part of the bore.

Considerable reduction in wear by chromium plating has been reported in many references in the literature, which agrees with the authors' experience. These data, however, in general relate to the question of wear reduction irrespective of cause. The matter has been investigated from the particular aspect of wear due to corrosion from sulphur. In carefully controlled comparative tests with a small high-speed engine, over a considerable running time and at a moderate jacket temperature, "porous" chromium plating of the liner has been found to reduce bore wear when running on a 1.5 percent sulphur fuel to about one-third that of an unplated liner. Corresponding tests with a 0.08 percent sulphur fuel showed a similar and possibly greater proportional reduction in wear. With either the plated or unplated liner, wear on the 0.08 percent sulphur fuel was approximately half that on the 1.5 percent sulphur fuel. Thus the disparity in relation to sulphur content still remained but was shifted by chromium plating to a lower and less significant wear level.

A proportionately greater reduction in wear with the plated liner might have been expected when running on the 1.5 percent sulphur fuel. That this was not actually the case may have been due to the fact that chromium plating achieves its beneficial results not so much by direct resistance to corrosion as by resistance to abrasive and attritious wear. An apparent resistance to corrosion may simply result from a reduction in the increased abrasive wear which follows from corrosion.

Although chromium plating of the liner caused a marked reduction in bore wear, the rings surprisingly showed no



Sulphur content of fuel, per cent	Jacket temperature, deg. C.	Running time, hours	
		Chromium plated	Cast iron
1·5	60	173	90·5
0·1	60	52	116·5
0·1	20	—	24
Total		225	231

Fig. 10. Comparison of Bore Wears with Porous-chrome and Nitrogen-hardened Cast-iron Cylinder Liners
4-inch bore × 4·5-inch stroke swirl chamber compression-ignition engine at 70 lb. per sq. in. b.m.e.p., 1,000 r.p.m.

corresponding reduction in wear. Again, when similar tests were run on 1.5 percent sulphur fuel with chromium-plated rings in an unplated bore, there was no reduction in wear. Identically treated rings, according to privately communicated information, have given good results in the field when tested in a large number of engines. The disagreement between laboratory and field tests may possibly be accounted for by the fact that wear due to dust is relatively much greater under service conditions and that in the latter case generally much lower sulphur content fuels were used, thus shifting the emphasis to the abrasive type of wear.

Whatever the explanation of the reduction in wear by chromium plating, and despite occasional failures, this process has much to recommend it and its

use seems likely to become more widespread. Incidentally, it is to be noted that when using chromium-plated liners increased side clearance on the pistons is required to achieve optimum results.

Neutralization of Corrosive Acids. Provided the corrosive acids can be neutralized, it is apparent that the ill-effects of sulphur in the fuel can be largely nullified. This indeed can be accomplished with some degree of success by the incorporation of organic metal salts either in the fuel or in the lubricating oil. Petroleum-soluble organic salts have been added to a 1.5 percent sulphur fuel in a concentration equivalent to 0.1 percent sodium, and under the conditions of test employed have been found effective to the extent of reducing cylinder wear to 60 or 70 percent. Under similar conditions of test this compares with a reduction of wear to 40 or 50 percent by desulphurizing the fuel. Cattaneo and Starkman (1948) have reported a reduction of wear to as little as 50 percent by the addition to the fuel of sodium in the form of an organic salt in the concentration equivalent to 3 percent of the sulphur, calculated on the basis of sodium sulphate as the end product.

It is apparent from these experimental data that satisfactory reductions in wear can be accomplished by concentrations of neutralizing agent very appreciably less than those theoretically required. Nevertheless the amounts are substantial. A concentration equivalent to 0.1 percent sodium means the addition of 2¼ lb. of sodium to 1 ton of fuel. Economically the cost of this is prohibitive when it is borne in mind that the sodium has to be prepared in a suitable form for incorporating in the fuel. Technically there is also the objection of inorganic ash deposits in the combustion chamber, although in these particular experiments, apart from being evident as incrustations on the crown of the piston, the deposits gave rise to no apparent trouble. Organic neutralizers are less satisfactory in that appreciably greater quantities are required. Fuel additives, therefore, while effective in reducing wear, would not appear, for the reasons outlined above, to offer an acceptable solution to the sulphur problem.

Incorporation of the neutralizing agent in the lubricating oil would seem a much more attractive proposition. In this case the additive is concentrated at the surfaces where it is required to prevent corrosion and so is able to exert its maximum effect. With fuel additives, despite the fact that quantities much less than those theoretically required are effective, it seems inevitable that a certain proportion must react in the combustion space with acid which otherwise would have passed harmlessly out of the exhaust. Such material to all intents and purposes is wasted. Lubricating-oil additives are much less subject to this disability although other wastages may occur due to oil consumption, to useful additive being discarded at the time of oil changes, and to other causes. Further, higher concentrations are required when the additive is incorporated in the lubricant, so that in actual fact comparable amounts of additive are consumed.

The beneficial effects of additives in heavy-duty oils are too well-known to require amplification. In the development of new and improved additives the sulphur problem has received special attention, and additives have been produced which are extremely effective in combating both the wear and fouling aspects (Edgar, Plantfeber, and Bergstrom 1948). Using the Coordinating Research Council's L-1 test procedure (1946), with the exception of operating at a low jacket temperature (100 deg. F.) and running only the first period when the oil is normally changed, results shown in Table 4 were obtained.

It will be observed that under these severe test conditions extremely good results were obtained with the additive-type oil, actually better than when running on the standard fuel and using the straight oil. The breakage of valve

springs was ascribed to surface corrosion effects and it will be noted that this trouble was absent when the additive was used.

Naturally, the additive is consumed in fulfilling its function, and in course of time a diminishing concentration is available to combat corrosion and fouling. Fresh additive is supplied with the make-up oil and ultimately the concentration will tend towards an equilibrium value considerably below the original. To maintain effectiveness, a fairly high initial concentration is found to be required unless the oil is frequently changed, which, naturally adds to the cost of the oil.

The foregoing applies essentially to engines in which splash feed allows large quantities of oil to reach the piston and liner. In the case of large engines, however, with separate cylinder lubrication, the oil supply and consequently the amount of additive reaching the cylinder are limited. As yet, little is known in respect of wear reduction, but fouling at least shows slight benefit from the additive. Reaction between additives and sulphur compounds is evident from examination of the cylinder drainings which would point to a possible reduction in wear.

TABLE 4. EFFECT OF ADDITIVE IN LUBRICANT

Fuel	Lubricant	Piston merit rating: 10 = clean 0 = dirty	Total ring loss of weight in 120 hours, grammes	Remarks
Specification fuel 0·43 per cent sulphur	Straight mineral oil	5·9	0·356	Medium carbon deposit in ring grooves. Slight corrosion of valve stems and broken valve spring.
1·3 per cent sulphur fuel	Straight mineral oil	4·7	1·022	Heavy carbon deposits in ring grooves. Severe corrosion of valve stems and springs and broken springs.
1·3 per cent sulphur fuel	Special heavy duty type oil	8·7	0·256	Very clean ring grooves and extremely slight corrosion of valve stems. Springs satisfactory.

Apart from this one aspect, suitable lubricating-oil additives in appropriate concentration show considerable promise and would appear one of the most satisfactory methods of combating the sulphur problem. Both wear and fouling are taken care of and owing to the fact that lubricating oil is a highly specialized product, marketed in a number of qualities and grades, its use is optional to the consumer depending on his requirements.

CONCLUSION

The effects of sulphur in Diesel fuel are, on the whole, unfavorable, and in view of the anticipated general increase in sulphur content of future fuels, disappointing results in Diesel operation can be expected unless timely counter-measures are taken. To meet the situation, the collaboration of the engine manufacturer, the engine user, and the oil supplier is required. Engine design can and should be adapted to the use of higher sulphur fuels, and due attention should be paid to operating conditions by the user. That in suitable engines, and with suitable precautions, high sulphur fuels can be satisfactorily used, is demonstrated by the engines of the Irak pipeline running since 1934 on a crude oil with 3 percent of sulphur, by an Anglo-Saxon tanker, the *Auricula*, running on a heavy 2.5 percent sulphur fuel, and by many other examples. The oil supplier from his side can offer appropriate additive-type lubricants. By such joint action can the sulphur problem be satisfactorily solved.

Acknowledgments. The authors wish to express their appreciation to the directors of the Royal Dutch-Shell Group Companies for permission to publish these data, and to record their indebtedness to the staffs of the Delft and Thornton laboratories responsible for carrying out the experimental work and collaborating in the preparation of this paper.

Appendix

References

Blanc, L. A., 1948 Quarterly Trans. Soc. Automotive Eng., vol. 2, p. 306, "Effect of Diesel Fuel Characteristics on Engine Deposits and Wear."

Boerlage, G. D., and Gravesteyn, B. J. J. 1932 *The Motor Ship*, vol. 13, p. 171, "Cylinder Wear in Diesel Engines."

Broeze, J. J., and Gravesteyn, B. J. J. 1938 *The Motor Ship*, vol. 19, p. 216, "Fuel and Wear in Diesel Engines."

Cattaneo, A. G., and Starkman, E. S. 1948 Massachusetts Inst. of Technology, "Fuel and Lubrication Factors in Piston Ring and Cylinder Wear."

Cloud, G. H., and Blackwood, A. J. 1943 Trans. Soc. Automotive Eng., vol. 51, p. 408, "Influence of Diesel Fuel Properties on Engine Deposits and Wear."

CRC Handbook 1946 (Coordinating Research Council, Inc., New York), p. 347.

Edgar, J. A., Plantfeber, J. M., and Bergstrom, R. F. 1948 Soc. Automotive Eng. Fuels and Lubricants Meeting, Tulsa, "Special Heavy Duty Type Engine Oils."

Hoegh, C. 1942 "Cylinder Wear in Diesel Engines" (Aschehong and Company, Oslo).

Johnstone, H. F. 1929 University of Illinois Engineering Experimental Station Circular No. 20.

Miller, E. F., and Nelson, F. L. 1947 National Oil and Gas Power Conference of the A.S.M.E., Cleveland, "The Diesel Fuel Situation." Digest in *Oil and Gas Jl.*, 1947, vol. 46, p. 82.

Moore, C. C., and Kent, W. L. 1947 Quarterly Trans. Soc. Automotive Eng., vol. 1, p. 687, "Effect of Nitrogen and Sulphur Content of Fuels on the Rate of Wear of Diesel Engines."

Ricardo, H. R. 1933 Diesel Engine Users' Assoc., "Some Notes and Observations on Petrol and Diesel Engines."

Taylor, A. A. 1942 Jl. Inst. Fuel, vol. 16, p. 25, "Relation between Dewpoint and the Concentration of Sulphuric Acid in Flue Gases."

Williams, C. G. 1940 "Collected Researches on Cylinder Wear" (Inst. Automobile Eng., London). Now issued by the Motor Industry Research Assoc.

SOME NOTES ON PATENT LAW

ACKNOWLEDGMENT

MR. R. D. HENSEN, instructor in engineering law, University of Illinois, is the author of this article reprinted from Mechanical Engineering for June 1950. It discusses some of the important elements of the patent law field.

In this paper an attempt has been made to touch on some of the important elements of the patent-law field, but many more have gone unmentioned. Whenever a problem arises in this field before the application for a patent is made as well as when litigation follows the issuance of a patent, always consult the very best patent attorney available. Cheap advice can be very expensive.

BASIC PATENT RIGHTS RESIDE IN CONSTITUTION

In Article I, Section 8, of the Constitution of the United States, it is provided: "The Congress shall have Power . . . To promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries . . ." This provision is the basis of federal jurisdiction over patents and copyrights, and pursuant to the authority therein delegated, the Congress has passed statutes governing these fields. A closely allied field is that of trade-marks, but the Federal Government was not granted exclusive control of this field by the foregoing Constitutional provisions. Federal jurisdiction in trade-marks must be based on some other clause in the Constitution, such as the interstate commerce clause.

A basic distinction between a patent, a copyright, and a trade-mark, is that a patent protects an invention or discovery, a copyright protects literary creations and works of art, while a trade-mark protects the name or emblem affixed to goods which are sold.

WHAT CONSTITUTES AN INVENTION?

United States Code, title 35, Sec. 31, states:

"Any person who has invented or discovered any new and useful art, machine, manufacture, or composition of matter, or any new and useful improvements thereof, or who has invented or discovered and asexually reproduced any distinct and new variety of plant, other than a tuber-propagated plant, not known or used by others in this country, before his invention or discovery thereof, and not patented or described in any printed publication in

this or any foreign country, before his invention or discovery thereof, or more than one year prior to his application, and not in public use or on sale in this country for more than one year prior to his application, unless the same is proved to have been abandoned, may, upon payment of the fees required by law, and other due proceeding had, obtain a patent therefor."

It will be noted that the statute requires an invention or discovery. Although often used synonymously, these words may be distinguished by using invention to refer to mechanical devices, and by using discovery to mean the observation of some principle or effect which has been in existence before but which was unknown.

The statute does not, and as a practical matter could not, state precisely what an invention is. That is largely left to the courts to decide on a case-by-case basis. In Kirsch Manufacturing Company v Gould Mersereau Company, Inc., 6 F. 2d 793, Judge Learned Hand said, "An invention is a new display of ingenuity beyond the compass of the routineer, and in the end that is all that can be said about it." A mere mechanical improvement which the average person skilled in the trade could have developed is not patentable. Nor can a mere change in the number of parts or a substitution of materials be patented, ordinarily. A combination of parts which produces a new result may be patented, but a mere aggregation of parts, each part performing its function as before with no joint action between parts is not patentable. An example of an aggregation is a lead pencil with an eraser on one end. Each part does the same work it did before, without co-operation. This aggregation was patented as a combination, but the patent was invalidated in Reckendorfer v Faber, 92 U.S. 347, and the court said, at page 357, "The combination, to be patentable, must produce a different force or effect, or result in the combined forces or processes, from that given by their separate parts. There must be a new result produced by their union; if not so, it is only an aggregation of separate elements."

The discovery that a particular substance will produce a new and desirable result may lead to an invention, but the discovery itself may not be patented. Dr. Morton's patent for the discovery of the effect of sulphuric ether in producing insensibility to pain was declared void in Morton v New York Eye Infirmary, Fed. case No. 9865. The court held: "In its naked ordinary sense, a discovery is not patentable. A discovery of a new principle, force, or law operating, or which can be made to operate, on matter, will not entitle the discoverer to a patent. It is only where the explorer has gone beyond the mere domain of discovery, and has laid hold of the new principle, force, or law, and connected it with some particular medium or mechanical contrivance by which, or through which, it acts on the material world, that he can secure the exclusive control of it under the patent laws. He then controls his discovery through the means by which he has brought it into practical action, or their equivalent, and only through them. It is then an invention, although it embraces a discovery."

Another element pointing toward invention is the commercial success which has attended the sale of the article. This becomes important when the patent is involved in litigation. The patent may involve a new method of achieving a result which has long been reached by other means, but if the patented article becomes widely used, that factor will point toward invention when the patent is questioned in court.

The question of what is invention is largely, in the end, uncertain. The court must make the final decision, and, in recent years, the standard of invention has been raised considerably.

TO BE PATENTABLE AN INVENTION MUST BE REDUCED TO PRACTICE

A further requirement for a patent is that the invention be new. In other words, it is essential that the subject of the patent be novel. An invention is not novel, by statutory provision, if it was known or used by others in this country before the date of invention by the applicant or patentee; or if it was patented or described in any printed publication in this or any foreign country before the date of invention or more than one year before the application for a patent; or if the invention was in public use or on sale in this country for more than a year before the application was made. (Before August 5, 1939, the one-year periods referred to were two-year periods.)

The date of invention ordinarily refers to the date when the idea was reduced to practice, but it may mean the date when the idea was first conceived, if that can be proved, and if the idea was diligently reduced to practice. The date of patent application is the date when the complete application is received and filed by the Patent Office.

Prior knowledge or use, to anticipate an invention or to invalidate a patent, must have been in the United States. An American may independently develop an invention which has been known or used abroad, but he may still obtain a patent, subject to the other statutory restrictions. A patent will not be invalidated because someone in the United States once thought about the same idea, if there was no reduction to practice, nor is it ordinarily fatal if the same invention has been accidentally discovered and used but unappreciated by its prior inventor, since it is the patentee who benefited the public by disclosing his invention.

It is possible that a patent may be granted for an invention, even though the same invention has been patented previously or described in a printed publication. This may happen through an oversight on the part of the Examiner in the Patent Office, and, even though a patent has been issued to the subsequent patentee, it can be invalidated by appropriate action.

For prior publication to anticipate an invention, the essentials of the invention must have been disclosed, and the publication must have been available to a large group, even though not to the public generally.

The claim of public use may be met by the defense of experimental use. In Elizabeth v Nicholson Pavement Co., 97 U.S. 126, a borderline case, the inventor of a new kind of paving with permission laid a section of the pavement as a part of a road traveled by the public, in order to test its usefulness, and this was held experimental use, although used for six years by the public before a patent was applied for, so the patent was valid.

A sale under the statute does not mean a sale of the invention itself, but rather a sale of some article embodying the invention.

As a general rule, only the first inventor is entitled to a patent, but the rule is subject to certain exceptions. If someone in China two thousand years ago developed a process which became lost in the intervening time, an inventor in the United States who rediscovered the process could patent it. Or someone might invent a device and later abandon it or use it secretly, and the same device might be developed later independently by another inventor; the latter would be entitled to a patent, since he has given his work to the public.

If two persons claim the same invention, the Patent Office will declare an interference and decide the priority of invention under the Rules of Practice, with the right of appeal to the courts. The Patent Office may declare an interference where two patent applications are pending for the same invention, or

where a patent has been issued and an application for a patent on the same invention is filed within a year after the first patent was issued. While the Commissioner of Patents cannot cancel a patent, he may, under Rule 93, grant a second patent for the same invention to a person who has been proved to be the prior inventor. If two patents claim the same invention, the interference may be tried in court.

One further requirement for patentability is utility. The invention must do something beneficial. If it can be used solely for an illegal purpose, it cannot be patented. The invention must be capable of performing some function, although it need not be perfect.

CONTRACT BETWEEN INVENTOR AND GOVERNMENT

A patent may be thought of as a contract between the inventor and the Government. In consideration of the inventor's disclosure to the public of his invention, the Government grants him an exclusive monopoly for seventeen years, during which time the inventor may use his invention or not as he chooses but he may prohibit others from using it. After the expiration of the seventeen-year period, the invention is open to the public for general use.

Only the actual inventor is entitled to a patent. If one person finances the work of another and an invention results, only the inventor is entitled to apply for a patent. If one person has an idea but the services of another are necessary to reduce the idea to practice, only the person who conceived the idea is entitled to a patent. If two or more persons jointly apply for a patent, each must have contributed to every claim of the patent in question, or else separate patents must be taken out by the persons inventing each claim. Where an employee is working for a corporation under a contract whereby his inventions are to become the property of the corporation, the employee making the invention must sign the application for a patent, and if anyone else does so, the patent will be invalid.

In the absence of any contract giving the employer any right in the inventions of his employees, there are two common situations. The employee may develop an invention on the employer's premises, using the employer's time and tools, and in this case, where the invention relates to the employer's business, the employer usually acquires a shop right. This means that the employee has a right to the invention, but the employer has a license—a personal right which is not assignable and not exclusive—to use the invention in his business for the life of the patent. If the employee develops an invention on his own time, using his own materials and tools, then he alone has a right to the invention, as a general rule, and may even sell the idea to a competitor of his employer.

For an employer to be entitled to the inventions of his employees, there must be a contract specifically providing for this, or else the employee must have been hired for the purpose of inventing. Even here, however, the invention must be in the line of company business, else the employer will have no claim on it.

THE PATENT APPLICATION

A patent application consists of the petition requesting a patent; the specification describing the invention and listing the claim made for it; the oath reciting that the affiant is the first and only inventor, and so on; and the official filing fee.

United States Code, title 35, sec. 33, requires that before an inventor shall receive a patent, he must file in the Pat-

ent Office a written description of his invention or discovery, and of the manner and process of making and using it "in such full, clear, concise, and exact terms as to enable any person skilled in the art or science to which it appertains, or with which it is most nearly connected, to make, construct, compound, and use the same; . . . and he shall particularly point out and distinctly claim the part, improvement, or combination which he claims as his invention or discovery."

The description must make a full disclosure of the nature of the invention so that one skilled in the art can reproduce it or use it, but the description need not be intelligible to the ordinary layman. The claims are the basis of the inventor's monopoly. They define the invention and the protection granted, but each claim is separate and independent. A drawing must also be submitted where the invention can be illustrated, and the size and kind of paper, the type of ink to be used, and so on, are all specified by the Patent Office.

When the application is received by the Patent Office, it is filed and assigned to the appropriate division concerned with this particular subject. When the examiner of the division reaches the application, he examines prior patents and literature and rejects any claims he feels are not justified, either because of prior patents or publication of the idea, or because the claims do not define the invention properly. After making his decision, the examiner notifies the applicant of his action, and the applicant has six months in which to reply, unless the examiner has set a shorter time. If the inventor chooses to rely on his original claims, he may do so; or he may cancel or amend the claims to which the examiner objected. Whether the claims are allowed by the examiner or by a higher tribunal on appeal, the patent will issue on the payment of the final fee. The final fee is the same as the fee paid at the time application is made for a patent: $30.00 plus $1.00 for each claim in addition to twenty, except in design patents. (Design patents are issued for "any new, original, and ornamental design for an article of manufacture . . . " under U.S. Code, title 35, Sec. 73, and are granted for the term of 3½ or 7 or 14 years, as the applicant may elect.)

PUTTING THE PATENT TO USE

After a patent has been issued, the problem arises as to what to do with the invention. The patentee need do nothing with it, but if he desires to profit by his invention, he will probably want to use it himself, or else he will want to allow others to use it under certain conditions. The patentee may desire to assign his rights to another by either a total or a partial assignment, that is, he may assign his entire rights or he may assign an interest in the patent, as a 1 percent or 90 percent interest. In the absence of an agreement to the contrary, the owner of a 1 percent interest has just as much right to exploit the invention as the owner of a 99 percent interest, or as the patentee himself. Assignments are provided for by statute, but the statute (United States Code, Title 35, Sec. 47) further provides:

"An assignment, grant, or conveyance shall be void as against any subsequent purchaser or mortgagee for a valuable consideration, without notice unless it is recorded in the Patent Office within three months from the date thereof or prior to such subsequent purchase or mortgage."

Under this provision, a subsequent purchaser for value and without notice of a prior assignment which has not been recorded at the time of the second assignment will, nevertheless, get nothing if the prior assignment is recorded within three months of the time when it was given.

The patentee may, instead of assign-

ing an interest in the patent, grant a license to use the patent. A license need not be recorded for a subsequent transferee of the patent to take subject to it. A license may limit the use of the invention in a number of ways. A nonexclusive license allows the patentee to exploit the invention himself or to license others to do so in addition to the first licensee. The license may be limited to a certain area or it may embrace the United States or the world, if foreign patents are contemplated. The license may restrict the licensee to a particular use, rather than allowing every use possible. A license may be limited in time for any period up to the life of the patent. It may require exploitation of the invention on penalty of forfeiture if this is not done. Such a license is a contract, and should be drawn carefully by a competent attorney specializing in patent problems, if the patentee wants to protect his rights.

An implied license is possible under some circumstances. One example of an implied license is a shop right, discussed in a previous section. Another instance where an implied license may arise is where a patentee sells a device to a customer, knowing the customer intends to use the device to make an article covered by the patent, and here the patentee may be estopped to deny the purchaser the right to make such use of the device for such purpose.

PROTECTION GIVEN A TRADE SECRET

Instead of securing a patent, an inventor or discoverer may rely on the common-law concept of trade secret. If an inventor uses his invention in secret, he may by injunction prevent others from using the invention, if they acquired their knowledge through a confidential relationship. If the invention is independently discovered or otherwise made public, the right to protection is gone. A manufacturing company may maintain its process as a trade secret rather than patent it, but if the process is not actually kept secret in so far as possible—as by warning employees not to divulge the process and by keeping visitors out of the plant—then it probably will not be entitled to protection if an employee leaves the company and decides to use the process himself. The protection given here is much less than is given a patentee, because the basis of the patent system is the benefit the public acquires by the inventor's giving his information to the world, and the man who wants to keep his knowledge secret deserves less protection.

FAMOUS PATENT LITIGATIONS

The following cases are well worth reading, either for the principle, the parties, or the inventions involved.

De Forest Radio Co. v General Co., 283 U.S. 664. A patent issued to Langmuir for exhaustion of occluded gases in a vacuum tube was declared invalid, partly on the ground that De Forest had anticipated him.

Edison v American Mutoscope and Biograph Co., 151 Fed. 767. This case involves Edison's patent for a kinetographic camera.

Edison Electric Light Co. v Novelty Incandescent Lamp Co., 167 Fed. 977. This case involves Edison's patent for a leading-in wire for incandescent electric lamps.

Edison Electric Light Co. v U.S. Electric Lighting Co., 52 Fed. 300. This case involves Edison's patent for an incandescent electric lamp.

Marconi Wireless Telegraph Co. of

America v De Forest Radio Telephone and Telegraph Co., 243 Fed. 560. This case invalidated De Forest's patent for a detector for wireless telegraph apparatus.

Root v Third Ave. Railroad Co., 146 U.S. 210. This case involves a patent for an "improvement in the construction of cable railways." The "improvement" was used in the construction of the cable railway on California Street in San Francisco, and this use was held not experimental, so the inventor's suit for infringement was dismissed.

Telephone cases, 126 U.S. This volume contains a series of cases involving Alexander Graham Bell's patent on the telephone.

REFERENCES

The following books are recent publications on patent law written primarily for interested persons other than lawyers:

"Inventions and Their Management," by A. K. Berle and L. Sprague de Camp, second edition, International Textbook o., Scranton, Pa., 1947.

"Patent Law," by C. H. Biesterfeld, second edition, John Wiley and Sons, Inc., New York, 1949.

"The Nature of Patentable Invention," by J. E. R. Hayes, Addison-Wesley Press, Inc., Cambridge, Mass., 1945.

"Patent Tactics and Law," by R. S. Hoar, third edition, The Ronald Press Company, New York, N. Y., 1950.

"Patent Fundamentals," by A. Schapp, The Industrial Press, New York, N. Y., 1939.

"Patent Law for the Executive and Engineer," by H. A. Toulmin, Jr., second edition, Research Press, Inc., Dayton, Ohio, 1948.

The following textbooks are recent publications in the field of engineering law; they contain short discussions on patent law:

"Business, Legal, and Ethical Phases of Engineering," by D. T. Canfield and J. H. Bowman, McGraw-Hill Book Company, Inc., New York, N. Y., 1948.

"The Engineer at Law," by C. B. McCullough and J. R. McCullough, The Iowa State College Press, Ames, Iowa, vol. 2, 1946.

"The Specifications and Law on Engineering Works," by W. C. Sadler, John Wiley and Sons, Inc., New York, N. Y., 1948.

APPLICATIONS FOR HELIUM IN INERT-ARC WELDING

ACKNOWLEDGMENT

MR. M. J. CONWAY, of the General Electric Company, Fitchburg, Mass., is the author of this article giving a historical review of the use of helium in inert-arc welding. It stresses the advantages and shows the future promise of that method. The article appeared in the July 1950 issue of the Welding Journal.

SUMMARY

Helium is one of the two monatomic gases which are practicable for inert-arc welding. The other is argon. Neon, krypton, xenon and radon are too rare and expensive.

Helium is not widely used in many applicable cases. Its use is preferable in welding stainless steel, inconel, Monel, cupraloy, silicon bronze and copper in all but the thinner gages.

At present, direct-current straight polarity is used most with helium; because it gives a more inherently stable and hotter arc.

Alternating current is used but little with helium at present; because higher voltage is required for arc stability, there is less arc heat per ampere, and conditions are more critical.

Henry M. Hobart of General Electric corresponded with associates about helium in welding in 1919, and he received one of the basic patents on inert-gas welding in 1930. However, commercial development of welding with helium was delayed until World War II, when it was used in welding magnesium and stainless steel.

Postwar development has been rapid. Helium was found preferable for welding some other difficult metals. The U. S. Bureau of Mines cooperated by constantly increasing helium purity to its present 99.99%, and by undertaking some of the practical welding research. Refinements of alternating current circuits give great promise, especially in welding aluminum. There is at least one application where helium has proved decidedly superior to argon in welding aluminum. Welding of other metals with helium as the inert gas and with either alternating or direct current sources is being investigated.

There is little doubt that a much wider application of helium in inert-arc welding is in the foreseeable future.

INTRODUCTION

The fact that helium is monatomic is important because it shows how exclusive, i.e., inert it is. It will not even unite with a fellow atom to make a molecule, as all active gases such as oxygen and hydrogen do, let alone combine with other kinds of atoms to form chemical compounds.

This is true even on the supertorrid surface of our sun. There, even hydrogen atoms undergo fission, thereby releasing the energy we get from the sun. The split hydrogen atom parts reunite into helium atoms. And there the action stops. The resultant helium will not break down or unite with anything on the sun, in spite of the tremendous heat and energy there.

It follows then that helium certainly will not break down or unite with anything under the influence of a welding arc. This makes it an ideal inert welding atmosphere.

While it is true that this inertness is shared by the five other monatomic gases —argon, neon, krypton, xenon, and radon—only argon approaches helium in relatively cheap and plentiful supply. When and if the others become even nearly so, their characteristics as welding atmospheres will no doubt be investigated.

The use of argon is too well known to require further comment here, except to dispel one pseudoscientific bit of fiction which has sometimes mitigated the use of helium. This fiction is that argon, being heavier than helium, even heavier than air, will lay down around and blanket the arc and molten metal better than helium. The facts are these: Argon is not significantly heavier than air; if it were it would displace the air and blanket the earth's surface to well over the average height of man. Argon does have an atomic weight nearly ten times that of helium (argon, 39.88; helium, 4.00). However, when heated to over 3000° C. by a welding arc, both gases tend to rise at a rapid rate. Shadowgraphs show little, if any, difference in this rate of argon or helium. Only the velocity of the gases and the flow pattern produced by the contour of the gas nozzles, or cups, seem to be effective factors in gas coverage. Argon and air are about the same weight, and we all know how even slightly hotter air rises. To re-express the point, hot gases rise, and the hotter the faster. Until we get working with radon, whose atomic weight exceeds that of mercury, the heaviness of the inert gas used in welding would seem insignificant.

PRESENT APPLICATIONS

Stainless Steel

The widest use of helium today is in the inert-arc welding of stainless steels. There are several good reasons: When used with a direct-current, straight-polarity source of welding power, welding speeds increase as much as 40% when helium is substituted for argon. Again, this speed is as much as 50% greater than when argon is used with an alternating current welding power source.

There is nothing mysterious about the attainment of these higher welding speeds. With helium the arc voltage per given arc length is at least 40% greater than with argon. Therefore, the wattage, or heat, in the arc is that much greater. Since the speed of welding is a function of the rate of heat input to the work, it follows that the hotter arc attained with helium produces faster welding. Only where the work is too thin or too small to take the higher heat of helium is the use of argon and direct current preferable for inert-arc welding of stainless steels.

Other advantages accrue with the

higher welding speed when helium is used. Distortion is reduced both directly because of the increased welding speed and also because of the reduction in width of the heat-affected zone and the weld bead itself. The narrower weld bead and heat-affected zone plus the faster fusion and chilling rates, decrease carbide precipitation and other undesirable metallurgical changes.

The use of reverse-polarity direct current to reduce heat input for small or thin work has, unfortunately, proved impractical. The reasons are: first, an extremely short arc length is required to maintain an arc; and second, the arc tends to wander over a fairly wide surface in a glow rather than a solid welding arc. This observation appears to be generally true whether helium or argon is used, and with other metals. The notable exception is magnesium, which welds nicely with helium and reverse-polarity direct current. This wide brush-type, unstable arc appears to be due to the electrical emission characteristics of various metals; i.e., their ability to give off electrons to form an arc when they are negative and a positive electric pole or point is brought near. It seems that most metals give off electrons, or emit, more readily than tungsten. Therefore, when the tungsten electrode is made positive, as it is in reverse polarity, it tends to pull the easily moved electrons off a wider surface of the electrically negative work. Moreover, certain small points on the workpiece are sufficiently good emitters that any solid part of the arc jumps from them rather than from the point directly under the electrode. These high emission points are called cathode spots. It is the arc's tendency to jump around to these cathode spots that makes it unstable. Of course, an extremely short distance between the electrode and the work limits this effect by narrowing the effected area.

The work done to date in using helium with an alternating current source to weld stainless steel has given inconclusive results.

Inconel and Monel

These two metals are also often welded with helium and direct-current straight polarity. Welding conditions and comments are similar to those for stainless steel. The only additional point worthy of attention is the fact that X-ray quality welds can be made in inconel and Monel with the inert-arc process. This remains true whether or not filler metal is added.

Copper and High-Copper Alloys

Here again helium has proved preferable to argon principally due to the hotter arc obtained with helium. This hotter arc requires less preheat, lower amperage welding current (often reducing the required equipment capacity) and gives the expected higher welding speed and reduced distortion.

Direct-current, straight-polarity power is preferred because in addition to a stable arc it gives the best division of arc heat—the majority going to the work, and comparatively less to the electrode. When copper's high capacity to absorb heat and conduct it rapidly away from the weld point are considered, the advantages of this greater arc heat input to the work becomes apparent.

Although some moderate success in welding copper and high-copper alloys has been obtained with argon and alternating current, results with helium and alternating current are inconclusive.

Welds in silicon bronze made by the inert-arc process, with helium as the inert gas, will meet A.S.M.E. Code U-68 for Unfired Pressure Vessels.

When inert-arc welding copper or high-copper alloys, it is preferable to weld uphill some 10 to 15° whenever possible. Otherwise, there is a tendency for the very fluid metal to flow ahead of the arc. This results in poor fusion and difficulty in laying in relatively heavy passes.

Brasses are weldable with helium if some zinc and color loss are permissible.

Aluminum

Helium is not used to any great extent in inert-arc welding of aluminum.

Helium can be used with direct-current straight polarity if flux is used. However, as soon as flux is used the chief advantage of inert-arc welding—freedom from flux handling and removal, possible flux inclusions and corrosion, and porosity—are lost. Joint design must then provide access for flux removal and neutralization to prevent corrosion. Even with straight polarity and flux, however, argon is still preferable for inert-arc welding aluminum.

Reverse-polarity direct-current welding of aluminum with this process has not proved practical under production conditions.

When using alternating current in inert-arc aluminum welding, helium has proved preferable to argon in making plug welds. (Plug welds are invaluable in permanently fastening aluminum strips or sheets to heavier aluminum structural members or bus bars.) The reason helium is preferable in this case is that the arc shows less tendency to burn back the edge of the hole in the thinner strip than when argon is used. This means that a neat fillet can be run around the edge of the hole before filler metal is added to complete the weld. This fact strongly suggests that helium and a.c. might be preferable to argon and a.c. in making lap welds in aluminum. This theory, however, is untested to date.

Helium and alternating current has consistently produced outside corner and edge joints in aluminum comparable to those produced with the more usual alternating current and argon. Work on other joint types in aluminum is not conclusive. For instance, practically no aluminum work involving filler metal addition has been done with helium to date.

Hard Facing

Some hard facing is now being done by the inert-arc process employing argon and straight-polarity direct current. This has proved equally satisfactory to and several times faster than gas welding for this purpose. The hotter helium-shielded arc may reduce the welding time required still more—that remains to be seen.

It must be apparent from the foregoing that although the use of helium with direct current is fairly well established in inert-arc welding, the helium and a.-c. combination is in the same developmental stage as was argon and alternating current five years ago. The development of the argon a.-c. combination in inert-arc welding is mostly history.

HELIUM HISTORY

Speaking of history, let us take a peek at the letter Henry M. Hobart of General Electric is reading—the date is March 7, 1919:

"Dear Mr. Hobart:

I have received your two recent letters regarding the use of helium gas in connection with arc welding.

I believe your scheme would work well and improve the quality of welding. At any rate, it is well worth trying. . . ."

However, basic research takes time and helium was hard to get and costly. So it was not until 1930 that Mr. Hobart was to receive and assign to the G-E Company the basic patent on inert-gas welding.

World War II arrived before development made the inert-arc process practicable. By then helium was being used with reverse-polarity direct current to weld magnesium aircraft parts. As the war progressed, helium and straight-polarity direct current were used for stainless steel and for aluminum welding with flux. However, before the war's end,

aluminum was being welded without flux using argon and alternating current.

After the war, intensive development of inert-arc welding was stimulated by three factors.

1. The steel shortage produced demands for better nonferrous metal fabrication methods.

2. Engineers and scientists were able to follow through on further theories and equipment development.

3. The U.S. Bureau of Mines, with a surplus of helium on hand, became interested.

The interest of the Bureau of Mines led first to cooperative investigation with Industry and then to the acquisition of equipment and further investigation in their own laboratories. This led to increasing the purity of helium further and further until today a purity of 99.99% has been attained.

This increased purity has proved worth while by decreasing and even eliminating many previous problems. (One of these was the elimination of porosity in inert-arc welded Monel).

As a result of this developmental work by the Bureau of Mines, helium of purity better than 99.9% or double-charcoal helium, is being furnished as standard for inert-arc welding.

FUTURE

The work the U. S. Bureau of Mines is doing in developing an a.-c. helium-aluminum welding technique looks very promising. Anyone who has seen samples resulting from this work would find it difficult in some cases to tell them from those made with the now standardized argon a.-c. process. Since aluminum has been one of the most difficult metals to weld by a fluxless process, it follows that perfection of an a.-c. helium technique for aluminum would undoubtedly open new fields of application for other metals.

In a recent issue of The Welding Journal an article appeared which indicated that Air Reduction company's work in developing gas-shielded metallic-arc welding was aided by the availability of double-charcoal helium. There is an excellent chance that helium may replace argon in this application for aluminum welding. In turn, the perfection of an aluminum-welding technique will allow the extension of development of the gas-shielded metallic-arc welding process to other metals. Surely, helium will be found preferable for some of these metals.

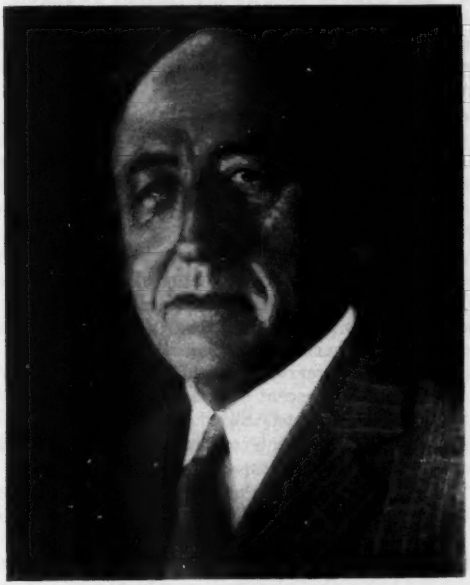
This is only one indication of the applied research being carried on both by the welding equipment industries and the metal fabricating industries. Some developmental work in gas-shielded welding is being carried on also by relatively disinterested organizations such as Battelle Memorial Institute.

All of this research and development certainly promises new uses for helium as its characteristics become well enough known to make further technique problems more predictable.

Equally certain is the continued interest of the U. S. Bureau of Mines as long as they are compelled to pump helium back into the ground in order to preserve it.

Helium at Amarillo, Tex., is as cheap as hydrogen and only 15% of the average delivered cost of argon. When helium is used in sufficient volume to reduce handling and shipping costs to nominal figures, a still greater use will be dictated by economy. Then, helium may regain the ascendency it had at the start of inert-arc welding.

In any event, some of the inert-gas welding problems that plague us today will undoubtedly be solved with the help of helium tomorrow.



LAWRENCE YORK SPEAR

Lawrence York Spear became a member of the American Society of Naval Engineers on January 13, 1906. He had been associated with the Electric Boat Company since 1902. At that time he had resigned his commission in the Navy to become naval architect and technical director in charge of design and construction for the boat company, the successor to the Holland Torpedo Boat Co. started by John Philip Holland, inventor of the first successful submarine.

He served as company vice president and director from 1904 to 1942, also assuming the presidency of its subsidiary, New London Ship and Engine Company from its beginning in 1911 until its absorption into the parent company in 1929. In 1942 he became president of the boat company, until 1947 when he relinquished the presidency and was elected board chairman.

In his predominant role in the company for more than 48 years, supported by his continual deep faith in the value of the submarine and his outstanding administrative and technical skill, Mr. Spear had been responsible for much of the successful development of the submarine for the navy.

His naval background was invaluable for enlisting support of such men as the late Rear Admiral W. W. Kimball and Admiral Dewey. He guided the corporation through the crucial between-the-wars period when it had to struggle for existence without a contract to build a submarine for the Navy until 1931. He was company president during World War II when the concern played such a vital role by producing more than half of the submarines completed during this time. Submarines proved to be one of the most important factors in the defeat of Japan.

Mr. Spear's early interests were in the Navy, ship construction in particular, and with this in mind he prepared for entrance requirements to Annapolis.

His Navy career began with a tour of sea duty in both the Atlantic and South Pacific from 1890 to 1891 aboard cruisers *Pensacola, Baltimore* and *Charleston.* Although this was the period just before the modernization of the Navy, the *Pensacola,* typifying the antiquated design, the latter two vessels aboard which he served were forerunners of the more modern steel cruisers soon to be constructed.

Mr. Spear's ability was indicated by his academy record. His personal enthusiasm in the project of modernizing the Navy resulted in his being selected for transfer from line officer to the construction corps. This country having no suitable training facilities at that time he was sent in 1891 to the University of Glasgow in Scotland, from which he graduated with a bachelor of science degree in 1893.

During the following nine years after working for a short period in the design section of the Bureau of Construction and Repair he served in varying capacities ranging from assistant superintendent of construction in his first assignment to superintendent of construction in his last in the following shipyards: Union Iron Works, San Francisco; Mare Island, Calif.; Moran Bros., Seattle; Bremerton Navy Yard, Washington, and finally as supervisor over both the Crescent shipyard of Elizabethport, N. J., and the Charles L. Seabury Consolidated Shipbuilding Co., Morris Heights, N. Y.

This construction work was interrupted during 1898 and 1899 by a brief tour as officer in charge of the post-graduate school of naval architecture at Annapolis. While at the Union Iron Works he supervised building of two best known ships of the Spanish-American War, the *Oregon* and the *Olympia.*

It was while superintending construction at the Crescent shipyard that Mr. Spear became primarily interested in submarines. At that time among other vessels under construction there were five Holland submarines of the "A" or "Adder" class which were to comprise this country's first undersea fleet. They were being built under contract to the Electric Boat Co., founded in 1899 for the purpose of providing capital for the Holland Torpedo Boat Co., which soon was absorbed into the former organization.

In 1902, foreseeing an opportunity to utilize his ability to its utmost in the development of a new weapon of indeterminable potentiality, Mr. Spear resigned his commission as lieutenant senior grade, in the Navy, beginning work in the field to which he would devote his remaining 48 years and to which he would make such vast contributions.

On June 2, 1902, Mr. Spear married Miss Lillian Wing, daughter of Charles Tudor Wing, a prominent New York banker and broker.

In the near half-century Mr. Spear played a predominant role in Electric Boat Co. This corporation built for the United States a total of 220 submarines. He personally had been responsible for many changes and improvements in design and construction methods that have transmitted the early small, dangerous craft into the vitally effective modern submarine of today. He is credited with six patented basic designs which are an integral part of all modern United States submarines. They include those in relation to stern construction, double hull amidships, single hull ends, propelling apparatus and two for hull construction in general.

Mr. Spear also was instrumental in the boat company's record of building more than 100 submarines for foreign countries, including England, Denmark, Austria, Spain, Chile, Peru, Canada, Norway, Italy and other nations. Some of these boats were built in this country, then disassembled and shipped abroad in knock-down condition, while others were finished in the United States and some were built abroad under the boat company's supervision.

The climax of Mr. Spear's career came in World War II when his great faith in the importance of the submarine was more than justified by the decisive role the Navy's undersea fleet had played in destroying the power of the Japanese. Here at last he could find reward for his thankless struggle between the wars to keep the boat company from foundering as a builder of submarines.

Here was justification for putting men to repairing hair curlers or even stamping out bobby pins, any type of work to keep a nucleus of his skilled workers together so the company would be able to serve its country in the time of need which he foresaw as not too far distant. The result of his perseverance is indicated by World War II records that show the U. S. submarine service, comprising only 1 6 percent of our Navy's total personnel, accounted for 63 percent of all Japanese merchant ships sunk in addition to 276 naval vessels.

At special exercises at the Submarine Base, April 11, 1947, Mr. Spear was presented by Admiral John Wilkes, then commandant of the Base, a certificate of merit "for outstanding fidelity and meritorious conduct in aid of the war effort against the common enemies of the United States and its allies in World War II."

This document had been signed by President Truman, September 25, 1946, and its dedication was a fitting tribute to the man who had done so much in spite of many difficulties, for the victory of his country.

In December 1949 Rear Admiral James Fife, in a speech on the occasion of the awarding of a watch to the honor student of the Base submarine school class in accordance with a foundation established by Mr. Spear in 1938, said of him, "Probably thousands of people have contributed to the modern submarine both operationally and in design development. I think of all those, the one outstanding individual of whom it can be said contributed most and who developed an international reputation in submarine design is Mr. Lawrence Y. Spear."

Mr. Spear had instituted this foundation with the intent of providing a continual stimulus for the wish to excel in scholarship among the students at the school. He also was instrumental in presentation to the Navy by the Electric Boat Co. of 16 stained glass windows for the newly constructed Submarine Base chapel at Pearl Harbor. These windows were dedicated at a Protestant service April 14, 1946, "To Our Heroic Submarine Dead."

In addition to his position with the boat company, Mr. Spear was a director of the Bed Rock Petroleum Co. He was a member of the American Society of Naval Architects and Marine Engineers, the American Society of Naval Engineers, and the American Society of Mechanical Engineers. He held membership in the Metropolitan and Wall Street clubs, both of New York, the Army and Navy, and Army and Navy Country clubs of Washington, D. C., and the Thames club and Submarine Base Officer's Club in New London, Connecticut.

Outside his work Mr. Spear had particular interest in golf, fishing, hunting and reading. He found time to make several valuable written contributions to the Society of Naval Architects and Marine Engineers, including the following: Bilge Keels and rolling experiments U.S.S. *Oregon* (1898); Submarine Torpedo Boats, past, present and future (1902); Development of Submarine (1906); The Submarine of Today and Tomorrow (1915); and The Submarine of Today (1927).

Mr. Spear's only survivor, besides his wife, is a brother, Frederick R. Spear of Geneva, N. Y.

The Society announces with deep regret the following deaths of which it has learned since the publication of the August Journal:

WILLIAM H. GREEN, Naval Member

H. C. ROACH, Naval Member

BERNARD SCOTT, Naval Member

LAWRENCE Y. SPEAR, Naval Member

HENRY A. ANSELL, Associate Member

CHANGES IN MEMBERSHIP

ERROR

The Society regrets that Wm. Francis Jameson, Jr., Chief Engineer, Condenser Service & Engineering Co., Inc., Hoboken, N.J.; Mail address 130 Tappan St., Kearny, N.J., was listed in the Membership List of May 1, 1950, as an Associate Member. Mr. Jameson is in fact a Civil Member.

NEW MEMBERS

The Society takes much pleasure in announcing that the following new members have been accepted since the publication of the August, 1950, issue of the Journal:

NAVAL

Alger, James Albert, Jr., Commander, U.S.C.G.,
1019 10th St., Apt. B-1, New Alexandria, Va.

Brady, Edward Michael, Lieutenant, j.g., U.S.N.R.,
U.S.S. Prairie (AD 15) c/o Fleet P.O., San Francisco, Calif.

Brady, Robert C., Lieutenant, j.g., U.S.N.R., Sales Engineer,
Farrel-Birmingham Co., Inc., Ansonia, Conn.

Callaway, William Franklin, Lieut. Comdr., U.S.N.,
U.S.N., Postgraduate School, Annapolis, Md.

Drane, Frederick W., Ensign, U.S.N.R.,
S.S. *Gibbes Lykes*, Lykes Bros. S.S. Co.,
Box 625, New Orleans, La.

Eastham, John Moise, Jr., Lieutenant, U.S.N.R.,
543 Mellie Esperon Building, Houston 2, Texas

Englund, Harry Wallace, Captain, U.S.N.,
6007 33d St., N. W., Chevy Chase, D. C.

Flanagan, John Wilfred, Lieutenant, U.S.N.R., Electrical Engineer,
Bonneville Power Administration, Portland, Ore.
Mail: 6742 N.E. Hancock St., Portland 13, Ore.

Hurd, Charles William, Lieut. Comdr., U.S.N.,
8-9 Garden Circle, Waltham 54, Mass.

Jones, Robert Hudson, Jr., Lieut. Comdr., U.S.N.R.,
Head Engineer, Radar Systems Branch, Code 820-A,
Electronics Design Div., Bureau of Ships, Navy Dept.
Mail: 3531 Martha Custis Drive, Alexandria, Va.

King, Harry Milton, Lieutenant, j.g., U.S.N.R.,
863 So. California Ave., Cavina, Calif.

Nickel, Maurice Bernard, Lieut. Comdr., U.S.N.R.,
Production Engineer, Industrial Bureau, Panama Canal
Mail: Box 2292, Cristobal, Canal Zone

Vallin, Everett C., Lieut., U.S.N.R., Dist. Mgr. Detroit Office,
Lord Mfg. Co., Erie, Pa.
Mail: 7310 Woodward Ave., Detroit 2, Mich.

Zeien, Charles, Ensign, U.S.N.R., Student
3045 85th St., Jackson Heights, N. Y.

CIVIL

Drake, Marcus, Partner, Kindlund & Drake, Naval Architects
17 Battery Place, New York 4, N. Y.

Legaré, Herman L., President, The Balco Yacht Co.
P. O. Box 4065, Dundalk 22, Md.

Mahler, Martin, Architect
930 Burlington Ave., Union, N. J.

Martucci, Nicholas L. A., Executive Vice President
and General Manager, Flexitallic Gasket Co.,
8th and Bailey Sts., Camden 2, N. J.

Voorhees, Edgar, Engineer, Mechanical Marine Co.,
17 Battery Place, New York 4, N. Y.

ASSOCIATE

Anchelatos, George, Commander, R.H.N.,
1 Apestadou, Pavlou St., Agia Parsakevi,
Athens, Greece

Chambers, George Haddon, Commander (E) Royal Navy
c/o British Navy Staff, 1910 K St., N. W., Washington, D. C.

Forkner, Amanda Louise, Editor, Technical Material,
Transportation Corps, U.S.A., Brooklyn Army Base
Mail: No. 2401, Hotel Shelton, 49th St. &
Lexington Ave., New York 17, N. Y.

Gibbs, Leland E., Manager Technical Service,
Revere Copper & Brass, Inc., Rome, N. Y.

Manzalillo, James Leon, Mech. Engr. Diesel Engine Div.,
Caterpillar Tractor Co.
Mail: 318 N. Perry Ave., Peoria, Ill.

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British Joint Services Mission (Navy Staff)
P. O. Box 165, Benjamin Franklin Station, Washington, D. C.

Perry, William George, Constrn. Comdr., R.N.,
Staff Construction Officer, British Joint Services Mission
(Navy Staff) P. O. Box 165, Benjamin Franklin Station,
Washington, D. C.

Ramsay, James Wilkie,
P. O. Box 269, Dunedin, New Zealand

TRANSFERRED ASSOCIATE TO CIVIL

Rettaliata, John T., Dean of Engineering,
Illinois Institute of Technology, Chicago 16, Ill.
Mail: 3300 So. Federal St., Chicago 16, Ill.

THE FOLLOWING HAVE RESIGNED:

NAVAL:

Billington, D. B.
Colton, E. B.
Hudson, Roy C.
Justice, R. R.
Pearse, R. L.
Phillips, George L.

CIVIL:

Gibson, William R.
Lippincott, S. S.
MacIntyre, James R.
Pennimann, A. L., Jr.

ASSOCIATION NOTES

ORIGINAL ARTICLES

The editor of the JOURNAL is most anxious to obtain manuscripts of original articles on subjects of interest to naval engineers. Any manuscript accepted for publication becomes the property of the Society which copyrights it upon publication. Authors are paid from $40.00 to $150.00 depending upon length, interest and professional value.

The rules for manuscripts are as simple as we can make them.

1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

5. Photographs may be negatives, but glossy prints are acceptable.

6. Include on a separate page a short biographical sketch(es) of the author(s). 50 to 100 words for each author is desired.

Manuscripts should be mailed addressed to:

Secretary-Treasurer
American Society of Naval Engineers
605 F St., N. W.
Washington 4, D. C.

Manuscripts accepted will not be returned unless specifically requested by the author. If returned, they will be in the condition which has resulted from the work of the printer and the engraver. Immediately following publication, the author is furnished 10 reprint copies of his article free of charge. Additional copies may be purchased from the Society if the request is received 30 days prior to the publication date which is the 25th of the issue month. Estimate of cost of additional reprints, which will vary with the nature of the article and the number of copies ordered, will be furnished on request as soon as possible after the article is set up.

Manuscripts not accepted will be returned, postpaid, by the Society.

Manuscripts which are accepted will be published in the earliest JOURNAL which has not yet been closed (60 days before publication) and for which insufficient material is already on hand.

Subject Matter and Authors

To assist the editor in programming future issues, the help of all members is solicited. To make it easy, the last page in this issue is readily detachable as you will find. This page has blanks for two entries.

(*a*) What subject would you, as a member, like to see covered by an article in the Journal.

and

(*b*) Who do you consider best qualified to prepare such an article authoritatively, and what is his address. (if you know).

Any of these forms which are filled in and mailed to the Society will be received with thanks and the editor will follow up to get the suggested articles prepared.

PHOTOGRAPHS

Photographs of current or historical interest to readers of the Journal are desired. Any which are accepted by the Society will be purchased by the Society at a standard price of $5.00 each. Such purchase *will not* include any copyright by the Society, but the contributor must hold the Society free from any charge of violation of any previous copyright.

NOTICE OF DEATHS

The Society has no satisfactory machinery for obtaining notice of deaths of members. It is particularly desired that we receive such notice upon the death of any past officer, past member of the Council or member of more than twenty years' standing with photographs and short obituaries. It will be appreciated greatly if any member who learns of the death of a member will advise the Secretary-Treasurer.

SOCIETY LAPEL BUTTONS

Shown below is an illustration of the lapel button of the Society. It is believed that it will be conceded that this is a very fine dignified insignia. It is one-half inch in diameter.

The oak leaves and lettering are red on a gold background.

It is available to all members at fifty cents (50c) each.

LIFE MEMBERSHIPS

Any member may now purchase a life membership under the following rules:

(*a*) Any dues paid for the year in which life membership is purchased will be credited to the cost of the life membership.

(*b*) Life memberships are non-transferable and terminate with the death of the member.

(*c*) No refund will be made on account of death or resignation of a life member.

(*d*) Life membership will vary in cost with the age of the member at his next birthday following application, as follows:

Over 55 years	$125.00
40 to 55 years	175 00
25 to 39 years	225.00
Under 25 years	250.00

(*e*) All life memberships paid in shall be protected by a transfer on the books of the Society of Series G, U. S. Government 2½ per cent bonds. Thus a life membership fund will be established. It will be credited with moneys paid in for life memberships and debited with the regular amount of annual dues for each life member each year.

LOCAL CHAPTERS

Local Chapters of the American Society of Naval Engineers may now be authorized by the Council. The following rules for recognition of Local Chapters have been adopted by the Council:

(*a*) Twenty or more regular members, Naval or Civilian, may apply for a Charter as a Local Chapter.

(*b*) Each application must be accompanied by a list of members and a copy of local By-laws. The latter must meet the following minimum requirements.

1. All financial dealings of the local Chapter must be independent of the Society and can in no way obligate the Society as a whole. The local chapter shall set up on a non-profit basis. All accounting shall be local.

2. Each active local Chapter shall receive from the Society a grant of $0.50 per year for each naval member, civil member or associate who resides in the local area and who associates himself with the local Chapter. This grant may be used by the local Chapter to defray any necessary expenses, including (a) Letterheads, (b) Notice cards, (c) Postage, (d) Minimum rental allowance, (e) Secretarial service (part time).

3. Any technical papers presented at local chapter meetings, shall be submitted to the Secretary-Treasurer of the Society for consideration for publication in the JOURNAL. Any paper accepted will be paid for at regular rates.

4. Each local chapter shall submit a quarterly report of its activities to the Secretary-Treasurer. These reports must reach Washington, D. C. prior to 15 January, 15 April, 15 July and 15 October. This report shall contain a list of active local members as of the first day of the quarter for the purpose of computing the amount of grant.

5. Associate members of the Society shall be eligible for membership in a Local Chapter, entitled to all the privileges of other members except voting and holding office.

ACKNOWLEDGMENT

The August 1950 issue of the JOURNAL failed to give complete acknowledgment of the reprinted article "Screwshaft Casualties—The Influence of Torsional Vibration and Propeller Immersion." The article was one of the joint papers presented before a meeting of members of both the Institution of Naval Architects and the Institute of Marine Engineers. The article appeared in the Transactions of both societies, and not merely the Institute of Marine Engineers, as the JOURNAL stated.

ANNUAL MEETING

The annual meeting of the Society was held in Washington, D. C. on Tuesday, 3 October 1950. The attendance was very good.

The following report from the nominating committee was received and accepted without change:

"October 2, 1950

Rear Admiral F. E. Haeberle, U.S.N., President,
The American Society of Naval Engineers, Inc.
Navy Department,
Washington, D. C.

My dear Admiral Haeberle:

The committee appointed by your letter of September 1, 1950, consisting of the writer, Captain Robert A. Smyth, U.S.C.G., Captain Walter L. Tann, U.S.N.R., Captain Walter B. Armstrong, U.S.N.R., and Mr. Francis H. Engel, hereby presents the following nominations for offices of the American Society of Naval Engineers for the calendar year 1951:

For President:

Rear Admiral David H. Clark, U. S. Navy

For Secretary-Treasurer:

Captain James E. Hamilton, U. S. Navy
Commander Robert B. Madden, U. S. Navy

For Member of Council:

Captain Rawson Bennett, U. S. Navy
Captain Fred W. Walton, U. S. Navy
Captain Joseph B. Duval, Jr., U. S. Navy

Captain William A. Dolan, Jr., U. S. Navy
Commander Clarence H. Campbell, U. S. Naval Reserve
Commander Frederick C. Wiesner, U. S. Naval Reserve
Mr. F. Charles Ruling
Mr. John C. Niedermaier

All applicable requirements of the Society By-Laws have been complied with in connection with these nominations.

Very truly yours,
THORVALD A. SOLBERG,
Rear Admiral, U. S. Navy
Chairman"

The President reported the receipt of the report of the auditing committee which is as follows:

"2 October 1950

Rear Admiral F. E. Haeberle
Bureau of Ships
Washington 25, D. C.

Dear Admiral Haeberle:

The committee which you appointed to audit the accounts of the Secretary-Treasurer of the American Society of Naval Engineers for the calendar year 1949, met at the home of Mr. A. G. Fessenden, Clerk of the Society, on 22 September 1950. The entire board was present, consisting of myself as chairman, and Captain W. B. Armstrong, U.S.N.R., and Mr. Charles G. Cooper (vice Mr. James W. Jenkins) as members, in accordance with your letter of 31 August, and the Secretary's memorandum to me of 12 September. The Secretary-Treasurer Captain James E. Hamilton was also present.

The committee determined that the accounts of the Society for the year 1949 are in order and have been carefully kept. A statement of the income and expenditures and a balance statement is appended, signed by members of the committee.

As chairman of the committee I sighted the Society's securities, a list of which is appended. The Secretary-Treasurer was also present at the sighting.

The committee recommends that the statements showing the financial record of the Society for 1949 be published in the next issue of the JOURNAL, as was done in 1948 for the first time in several years, in order that the full membership can see the extent of the Society's business, which this year incurred a deficit of $12,100, as well as have additional proof that the increase of dues voted by the members was a necessity if the high quality of the JOURNAL was to be maintained. The effect of increased dues will of course not be realized until the audit of calendar 1950, the year the change was initiated.

Very respectfully,
FRANK C. JONES."

The American Society of Naval Engineers, Inc.

Financial Statements, 1949

Trial Balance

Cash		$ 2962.95	
Accounts Receivable:			
Advertisements	$ 2153.20		
Dues	5124.85		
Sales	152.98		
Subscriptions	1995.90	9426.93	
Investments:			
U. S. Defense Bonds, Series G	$58000.00		
Washington Gas Light Co. Bonds	997.50	58997.50	
Furniture		106.00	
Income (Publication):			
Advertisements	$ 5817.50		
Dues	15298.75		
Sales (General)	381.06		
Sales (Society Lapel Buttons)	28.00		
Subscriptions	8438.50		$ 29963.81
Expenditures (Publication):			
Printing	$27358.74		
Engraving	2880.14		
Manuscript	3003.00		
Postage	810.98		
Commission	101.50	34154.36	
Interest on Investments			1662.50
Banquet, 1949		23.42	
General Expense		3149.50	
*Salaries		4284.00	
Current Profit and Loss		2125.00	
Dues in Advance			258.75
Subscriptions in Advance			4455.15
Advertisements in Advance			235.00
Capital Account			78654.45
		$115229.66	$115229.66

* Error of $1.00 each month beginning Sept. 1949, in salary of Clerk; not discovered until March, 1950, when $6.00 deduction was made to cover. (See Cash Book 3-30-50).

Statement of Income and Expenditures

Expenditures

Publication:			
Printing		$27358.74	
Engraving		2880.14	
Manuscript		3003.00	
Postage		810.98	
Commission		101.50	$34154.36
Salaries			4284.00
General Expense			3149.50
Banquet, 1949			23.42
Current Profit and Loss			2125.00
			$43736.28

Income

Publication:			
Dues	$15298.75		
Advertisements	5817.50		
Sales, General	381.06		
Sales, Society Lapel Buttons	28.00		
Subscriptions	8438.50		
		$29963.81	
Interest on Investments		1662.50	31626.31
NET LOSS			$12109.97

BALANCE STATEMENT

Total Assets January 1, 1949.....			$78654.45
Assets December 31, 1949:			
Cash		$ 2962.95	
Accounts Receivable:			
Advertisements	$ 2153.20		
Dues	5124.85		
Sales	152.98		
Subscriptions	1995.90	9426.93	
Investment (Bonds):			
U. S. Defense, Series G.....	$58000.00		
Washington Gas Light Co. Bonds.....	997.50	58997.50	
Furniture		106.00	
		$71493.38	
Liabilities (Accounting Only):			
Advertisements paid in advance.....	$ 235.00		
Dues Paid in advance	258.75		
Subscriptions paid in advance	4455.15	4948.90	
Total Net Assets December 31, 1949.....			66544.48
NET LOSS			$12109.97

Respectfully submitted

J. E. HAMILTON, *Secretary-Treasurer*

Audited and Found Correct:

FRANK C. JONES
W. B. ARMSTRONG — Audit Committee
CHARLES G. COOPER

A motion was made and carried to continue in 1951, the custom of holding an annual banquet. The Secretary announced that a tentative reservation had been made at the Statler Hotel for Friday, 27 April 1951.

A motion was made and carried to submit to the membership a proposition to amend the by-laws to provide that the Undersecretary of the Navy, the Assistant Secretary of the Navy for Air, the Chief of Naval Material and the Chief of Naval Research be added to those officials who shall be ex-officio Honorary Members. This proposition will be found on the ballot which was recently mailed.

23 Fast Tankers

all with General Motors Diesel-Electric Drive!

PROOF of the economy and efficiency of Diesel-Electric Drive is provided by the Navy AOG-type oilers. Built to transport fuel and lube oil for aviation and small craft use, these medium-sized tankers carry 2,000-ton cargoes at 14½ knots—*with remarkable economy in fuel consumption*. Considering the size of ships' personnel complement —with necessary space and supplies —these ships' records are all the more important. Construction, under Navy design and specifications, was by Seattle-Tacoma Shipbuilding Co., of Tacoma, and Cargill, Inc., of Savage, Minnesota. Powered by GM Diesels.

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Results, supported by performance of actual installations operating under severe conditions, indicate that ANACONDA Cupro-Nickel 754 (U. S. Patent No. 2,074, 604) tube and sheet alloy gives economical service for central station and marine condensers handling clean and some types of polluted sea waters.

For details, or consultation with ANACONDA Condenser and Heat Exchanger Tube specialists, please address The American Brass Company, Waterbury 20, Connecticut. In Canada: Anaconda American Brass Ltd., New Toronto, Ont. 49125A

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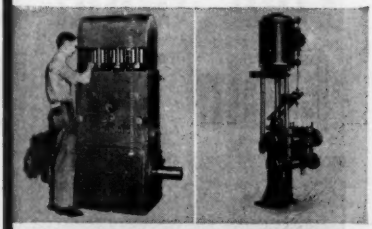

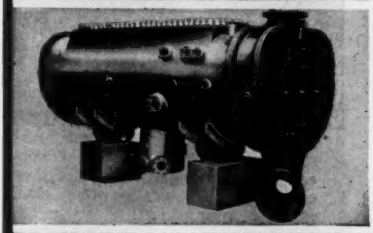

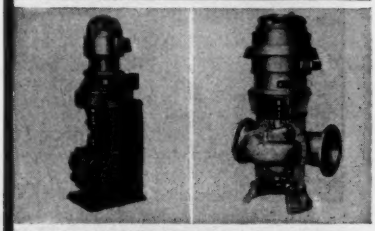

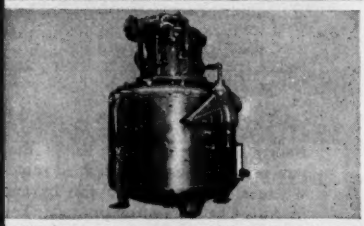

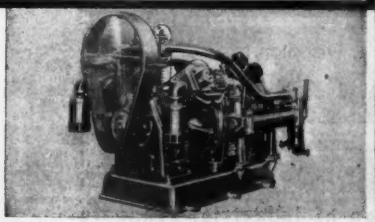

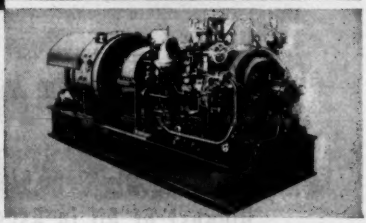

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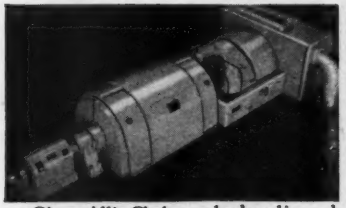

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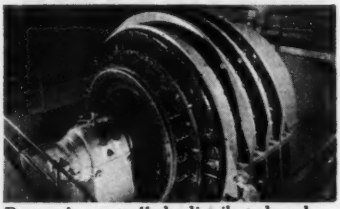

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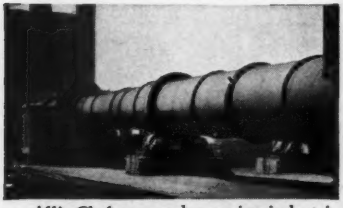

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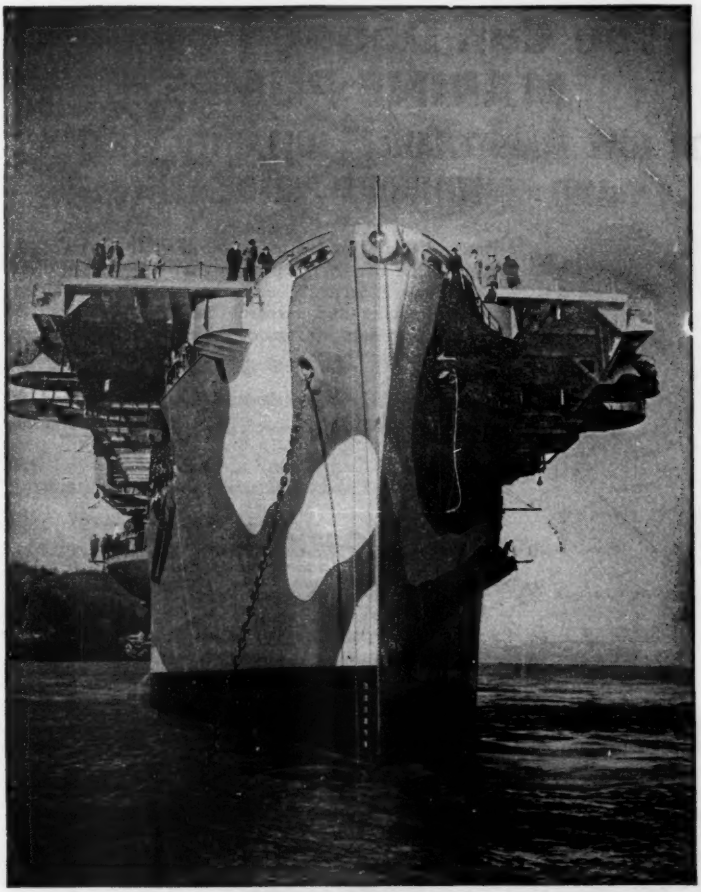

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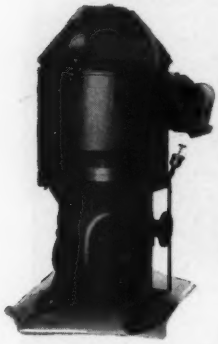

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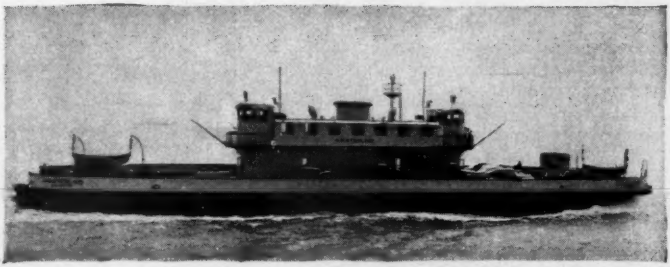

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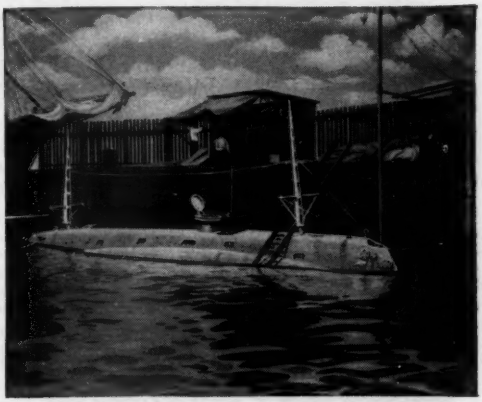

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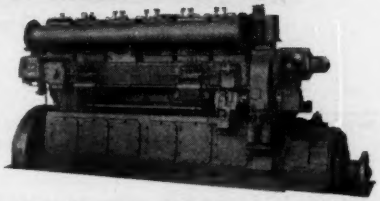

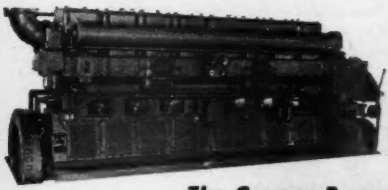

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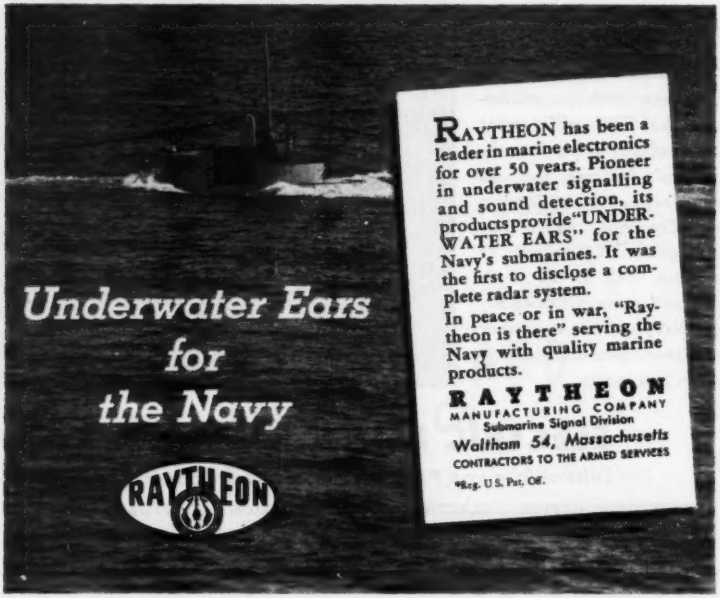
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QQ-P-416	"Lithoform," "Zinodine"
RR-C-82	"Lithoform" No. 32
MIL-C-5541 (See also QPL-5541-1)	"Alodine"
MIL-S-5002	"Alodine," "Granodine" (Dip, Spray and Brush grades)
JAN-C-490, Grade I	"Granodine" (Dip, Spray and Brush grades)
JAN F-495	"Granodine" (Dip, Spray and Brush grades), "Lithoform"
JAN-L-548	"Permadine"
AN-E-19	"Alodine," "Zinodine"
AN-F-20	"Alodine," "Granodine" (Dip, Spray and Brush grades), "Lithoform," "Permadine," "Thermoil-Granodine," "Zinodine," (See also U.S.A. 3-213)
U.S.A. 57-0-2	
Type II, Class A	"Thermoil-Granodine"
Type II, Class B	"Permadine"
Type II, Class C	"Granodine" (Dip, Spray and Brush grades)
U.S.A. 51-70-1	
Finish 22.02, Class A	"Thermoil-Granodine"
Finish 22.02, Class B	"Permadine"
Finish 22.02, Class C	"Granodine" (Dip, Spray and Brush grades)
U.S.A. 50-60-1	"Granodine" (Dip, Spray and Brush grades)
U.S. Navord O.S.675	"Alodine"
U.S.N. Appendix 6	"Lithoform"
Navy Aeronautical M-364	"Permadine," "Thermoil-Granodine"
AN-C 170	(See MIL-C-5541)
U.S.A. 72-53	(See AN-F-20)
AXS-1245	(See JAN-C-490)

Rust Removing and Metal Conditioning Chemicals

SPECIFICATION NUMBER	ACP SPECIFICATION CHEMICAL
JAN-C-490, Grade II	
Type 4	"Deoxidine" Nos. 126, 512, 526, 624, 670
Type 5	"Deoxidine" Nos. 170, 171, 670
U.S.A. 3-213	
Type I	"Deoxidine" (Wash-off grades)
Type II	"Deoxidine" (Wipe-off grades)

Metal Cleaning Chemicals

SPECIFICATION NUMBER	ACP SPECIFICATION CHEMICAL
JAN-C-490, Grade II	
Type 2	"Ridoline"
Type 6	"Ridosol"
U.S.A. 3-192	"Ridoline" No. 3192
U.S.N. Appendix 6	"Deoxidine"

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